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UARS In-Flight Jitter Study for EOS

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Princeton, New Jersey

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**UARS JITTER STUDY
FINAL REPORT**

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Anthony Camello was the PMO contact at GE Astro Space. Other members of the GE team who made significant contributions to the study are David Breskman, George Wang, Eric Tate, and George Futchko.



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ACS	Attitude Control System
C.G.	Center of Gravity
CMI	Consistent Mode Indicator
EMAF	Engineering Major Frame
EOS	Earth Observing System
ERA	Eigensystem Realization Algorithm
FEM	Finite Element Model
HALOE	Halogen Occultation Experiment
HGA	High Gain Antenna
HRDI	High Resolution Doppler Imager
IM	Instrument Module
MACS	Modular Attitude Control System
MLS	Microwave Limb Sounder
MMS	Multimission Modular Spacecraft
MSS	Multi Spectral Scanner
PSD	Power Spectral Density
RWA	Reaction Wheel Assembly
S/A	Solar Array
SSPP	Solar Stellar Pointing Platform
TM	Thematic Mapper
UARS	Upper Atmosphere Research Satellite

INTRODUCTION

Instrument bore site jitter, or the rotational response of an instrument to a disturbance, must be within acceptable limits if maximum instrument performance is to be expected. Typically, considerable analytical work is performed to predict jitter and ensure it meets specifications. Response data collected from gyroscopes (gyros) on board the Upper Atmosphere Research Satellite (UARS) provided a unique opportunity to analyze actual flight jitter.

The objective of this study was to analyze flight jitter data from the UARS spacecraft and perform analytical correlations. The gyro data was analyzed for frequency content to obtain the spacecraft modal characteristics. Flight modal parameters were compared to those obtained from a computer finite element model (FEM). Responses from various spacecraft disturbances were measured and compared to predictions obtained from a computer simulation of the disturbance.

The flight modal frequencies matched well with those obtained from the FEM. The spacecraft response to the MLS disturbance exhibited excellent correlation to the analytical simulation after measured flight damping values were used.



INTRODUCTION

OBJECTIVE

- DEMONSTRATE ON-ORBIT JITTER CHARACTERISTICS FOR A GENERIC LARGE POINTING PLATFORM

APPROACH

- MEASURE UARS ON-ORBIT DATA FOR VARIOUS SPACECRAFT DISTURBANCES
 - ANALYZE DATA TO OBTAIN SPACECRAFT MODAL CHARACTERISTICS
 - COMPARE THE ON-ORBIT JITTER RESPONSES WITH RESPONSES FROM MODEL PREDICTIONS

RESULTS

- OBTAINED EXCELLENT FREQUENCY CORRELATION WITH FLIGHT MODAL PARAMETERS
- STUDY SHOWED EXCELLENT CORRELATION FOR MLS AND HDRI CALIBRATION DISTURBANCES USING MEASURED FLIGHT DAMPING VALUES

UARS ORBITAL CONFIGURATION

In 1976, Congress amended the Space Act, directing the National Aeronautics and Space Administration (NASA) to undertake a comprehensive program of research into the upper atmosphere. The Upper Atmosphere Research Program was designed in the response to that directive. UARS, launched into space on September 12th 1991 aboard the space shuttle Discovery, is a low Earth orbiting observatory and the first critical step in NASA's "Mission to Planet Earth".

The major objectives of UARS are to understand the energy input, chemistry and dynamics of the upper atmosphere, its response to naturally occurring and human caused changes, and its role in climate and climatic variability. An international array of ten instruments was selected to satisfy these requirements. These instruments provide a comprehensive set of atmospheric measurements including observation of winds, temperature, pressure, gas species and concentrations, solar irradiance, and energetic particles.

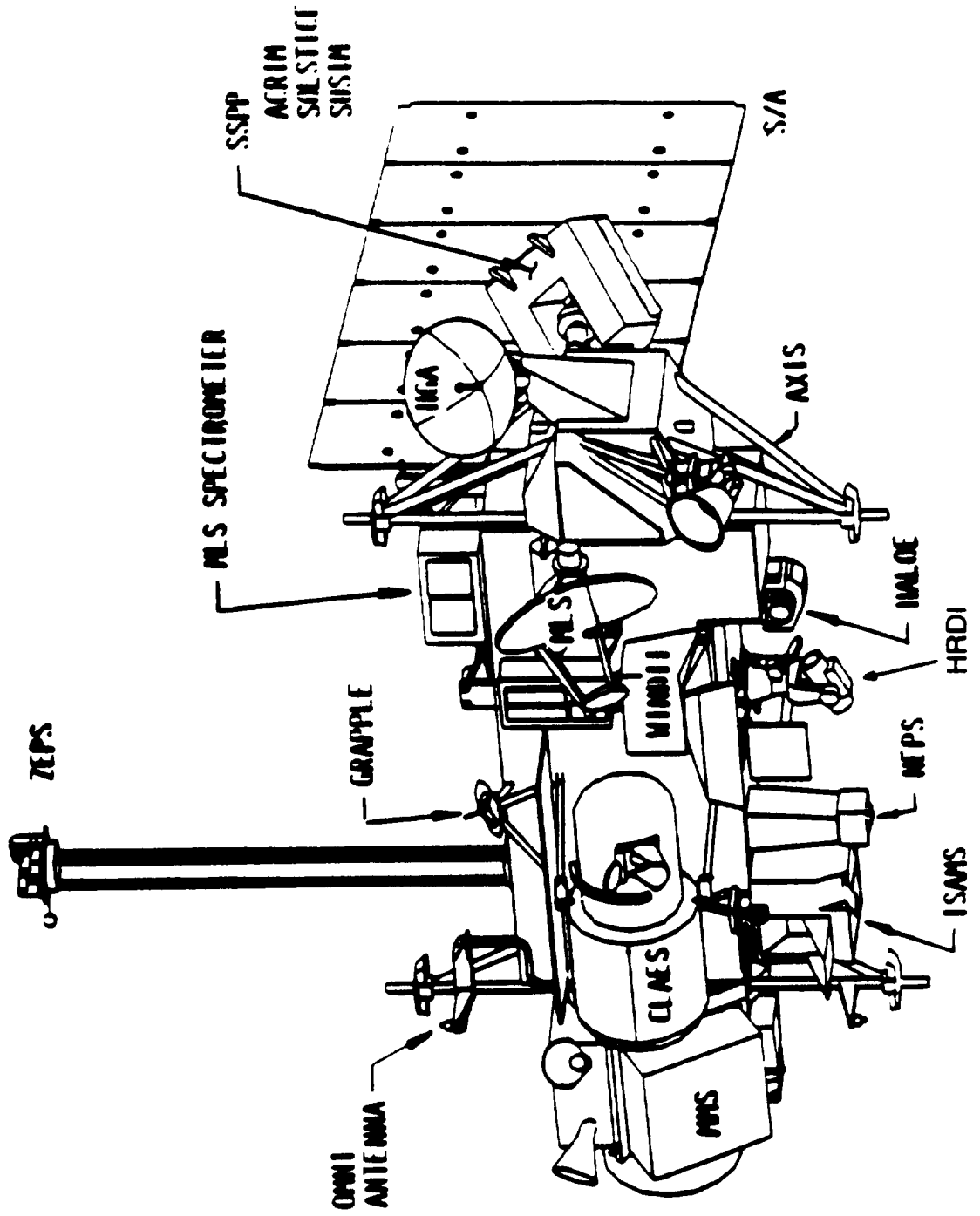
The UARS observatory consists of a standard Multimission Modular Spacecraft (MMS) coupled to an Instrument Module (IM) that includes the ten science instruments and various unique components. The observatory is illustrated in the chart below. It is approximately 32 feet long and 15 feet in diameter with a weight of approximately 14400 lbs.

Housekeeping functions are provided by the MMS including the Attitude Determination and Control System (AD&CS), communication and data handling, and electrical power storage and regulation. Mission unique equipment includes the IM structure, the solar array, the high gain antenna and omnidirectional antennas, an RF interface box, a power switching unit, and the solar stellar pointing platform (SSPP).

UARS is in a 585 km near circular orbit with an eccentricity of 0.0013 and in inclination of 57 degrees. The argument of perigee is frozen at 90 degrees to minimize altitude variation over the northern hemisphere. The orbital plane precision rate is 3.9 degrees per day.



UARS ORBITAL CONFIGURATION



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UARS JITTER STUDY

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UARS ORBITAL FINITE ELEMENT MODEL

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ORBITAL MODEL

A large and detailed structural finite element model of the UARS spacecraft was available from a previous jitter study conducted in 1988. The model simulates the spacecraft in the in-orbit configuration with the solar array, ZEPS Boom, and instruments in the deployed position.

The Instrument Module (IM) FEM as well as the deployed solar array (S/A), High Gain Antenna (HGA), and Solar Stellar Pointing Platform (SSPP) FEMs were generated by GE-ASD. Instrument FEMs were supplied by the individual instrumentors.

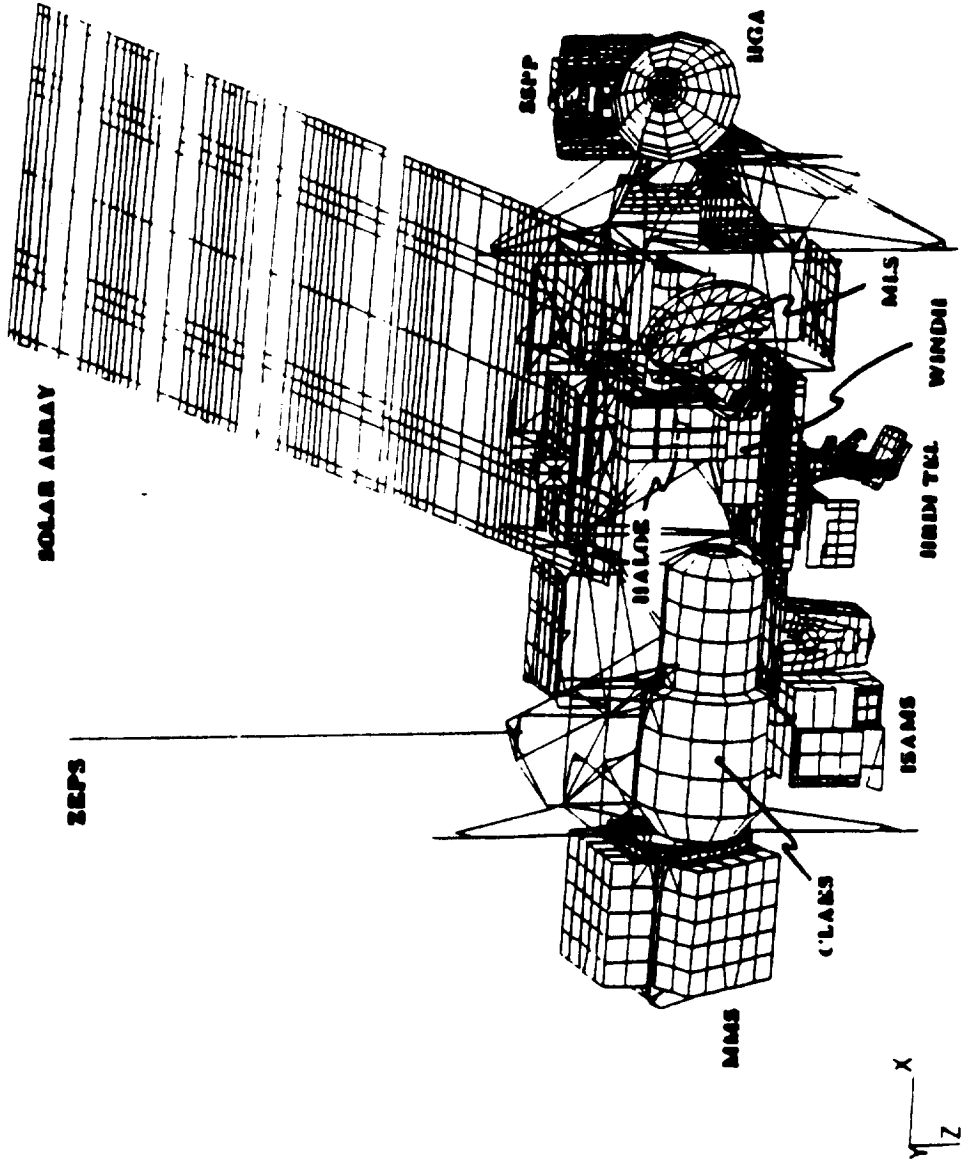
To reduce computer CPU time, the individual instrument FEMs were reduced to Craig-Bampton models and then combined with the IM using the Benfield-Rhuda modal synthesis technique. Modal synthesis was performed using NASTRAN DMAP written by GE-ASD.

The FEM passed the standard set of GE-ASD checkout tests. All FEMs generated at GE-ASD must pass the equilibrium check, the enforced displacement check, and the 3 axis 1-g static run. The equilibrium check ([K][RB]) is made to insure that the structure is not grounded, i.e., structurally connected to the frame of reference. In the enforced displacement check, the model is freed from all single point constraints (SPC's) and a single point on the structure is subjected to a unit displacement in each basic model direction (six subcases). The model has to "stay together" without generating any internal forces. Deformed structure plots are made to insure rigid body motion for each subcase. In the final checkout run (3 axis 1-g static run), the model is configured with its full boundary conditions and subjected to three separate uniform gravity loads, one in each orthogonal direction along the model basic axes. Since the orbital model has no boundary conditions, the spacecraft was fixed at the spacecraft/launch vehicle interface for this checkout run. A number of checks were made on the output from the 1-g run including checking the (6X6) weight matrix, center of gravity (C.G.), inertias, SPC forces, maximum displacements, visual checks on the deformed structure plots, as well as checking internal diagnostics such as warning messages, MAXRATIOS, and EPSILON values.



ORBITAL MODEL

NASTRAN FEM



- OVER 45,000 DOFS
- 12 SUBSTRUCTURES INCLUDING IM
- CRAIG-BAMPTON MODAL SYNTHESIS

ORIGINAL MODEL GENERATED IN 1988 TO PERFORM JITTER ANALYSIS

BASELINE ORBITAL MODEL (1988)

The baseline 1988 model is documented in Program Information Release (PIR) U-1K20-UARS-1063. 1988 was still relatively early in the design and the FEM weight distribution was based on the current design. The total orbital weight in 1988 was 14966 pounds.

A dynamic model consisting of 106 physical degrees of freedom and 280 mass normalized modes was obtained from the structural finite element model. The 106 physical degrees of freedom constitute the points of interest, such as instrument locations and disturbance source locations. Spacecraft modes up to 100 Hz were retained for the jitter analysis.

The 280 mass normalized modes include 6 rigid body modes of the unconstrained spacecraft structure. The first three spacecraft flexible modes are modes of the solar array. In addition, ZEPS, SSPP, and HRDI Telescope all have modes less than 4 Hz.

**BASELINE ORBITAL MODEL (1988)****ANALYTICAL PREDICTIONS WITH S/A AT 90 DEGREE POSITION**

SPACECRAFT WEIGHT 14966 LB

<u>MODE</u>	<u>FREQ (HZ)</u>	<u>DESCRIPTION</u>
1-6	0	RIGID BODY MODES
7	0.263	S/A 1ST FLATWISE BENDING
8	0.275	S/A 1ST EDGEWISE BENDING
9	0.677	S/A 1ST TORSION IN Y
10	0.794	ZEPS BOOM 1ST BENDING IN X
11	0.843	ZEPS BOOM 1ST BENDING IN Y
12	1.17	S/A 2ND FLATWISE BENDING
13	1.70	SSPP ROTATION ABOUT Y (ALPHA)
14	1.73	S/A 2ND TORSION ABOUT Y
15	1.82	SSPP ROTATION ABOUT X (BETA)
16	2.11	S/A 3RD FLATWISE BENDING
17	2.35	ZEPS 1ST TORSION ABOUT Z
18	3.19	S/A 3RD TORSION ABOUT Y
19	3.50	HRDI TEL TORSION ABOUT Z (AZIMUTH)
20	3.56	HRDI TEL TORSION ABOUT Y (ZENITH)
21	3.83	S/A 4TH FLATWISE BENDING

ORIGINAL JITTER PREDICTIONS BASED ON 1988 FEM

UPDATED ORBITAL MODEL (1992)

The weight of the 1988 orbital FEM was updated to match the launch weight. In addition, the solar array FEM was tuned to match results from a static load deflection test. The test measured both the static edgewise and flatwise stiffness. The FEM was updated to account for the test results and an increase in the solar array weight. None of the other substructure FEMs were test verified.

The solar array flatwise frequency did not significantly change in the updated model. However, an increase in weight coupled with a decrease in the yoke stiffness accounted for a 17% reduction in the edgewise frequency.

**UPDATED ORBITAL MODEL (1992)****ANALYTICAL PREDICTIONS WITH S/A AT 90 DEGREE POSITION**

ORIGINAL MODEL		UPDATED MODEL		DESCRIPTION
MODE	FREQ (HZ)	MODE	FREQ(HZ)	
1-6	0	1-6	0	RIGID BODY MODES
• 8	0.275	7	0.232	S/A 1ST EDGEWISE BENDING
• 7	0.263	8	0.262	S/A 1ST FLATWISE BENDING
9	0.677	9	0.716	S/A 1ST TORSION IN Y
10	0.794	10	0.794	ZEPS BOOM 1ST BENDING IN X
11	0.843	11	0.844	ZEPS BOOM 1ST BENDING IN Y
12	1.17	12	1.15	S/A 2ND FLATWISE BENDING
		13	1.18	S/A SUPPORT TUBES
13	1.70	14	1.70	SSPP ROTATION ABOUT Y (ALPHA)
15	1.82	15	1.82	SSPP ROTATION ABOUT X (BETA)
16	2.11	16	2.07	S/A 3RD FLATWISE BENDING
17	2.35	17	2.35	ZEPS 1ST TORSION ABOUT Z
• 14	1.73	18	2.67	S/A 2ND TORSION ABOUT Y
19	3.50	19	3.50	HRDI TEL TORSION ABOUT Z (AZIMUTH)
20	3.56	20	3.56	HRDI TEL TORSION ABOUT Y (ZENITH)
21	3.83	21	3.82	S/A 4TH FLATWISE BENDING
• 18	3.19	22	4.41	S/A 3RD TORSION ABOUT Y
14966 LBS		14410 LBS		

• INDICATES MODES SWITCHED

1988 FEM UPDATED TO MATCH LAUNCH WEIGHT DISTRIBUTION

FEM SUBSTRUCTURES

A weight comparison for the twelve different substructures is shown. The number of modes and physical degrees of freedom used for the coupled spacecraft analysis is also shown for each substructure. The spacecraft modal model has 280 modes below 100 Hz.



FEM SUBSTRUCTURES

SUBSTRUCTURE ID	WEIGHT (LBS)		NO. MODES UP TO 200 HZ	NO. ASSET DOFS
	1988	1992		
IM	6672	6106	194	583
ISAMS	419	348	48	293
HALOE	197	200	7	78
MLS	381	378	24	139
CLAES	2890	2704	50	402
HRDI	173	166	12	162
HGA	129	248	20	134
WINDII	308	284	16	108
SSPP	757	937	38	295
S/A	124	111	72	222
HRDI TEL	2450	2417	14	204
MMS	466	511	15	213
TOTAL	14966	14410	510	2833

MODAL MODEL HAS 280 MODES UP TO 100 HZ

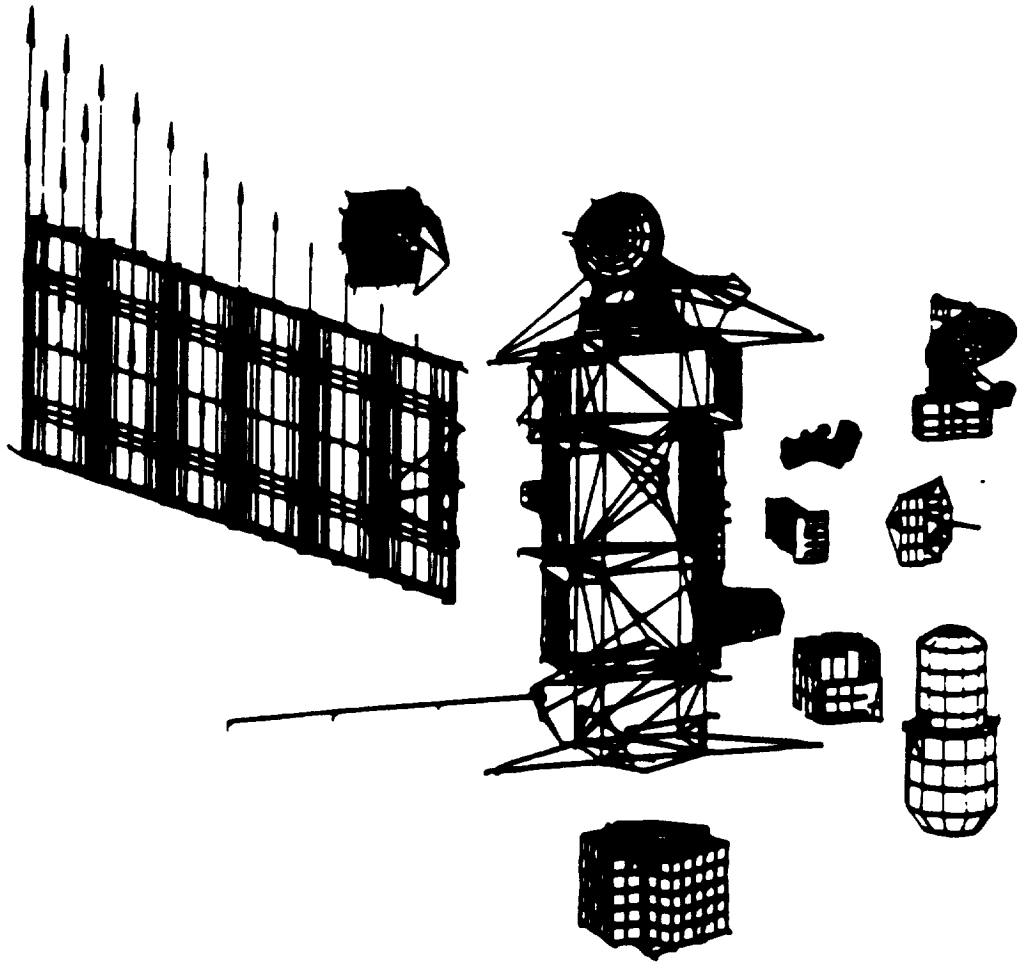
SOLAR ARRAY FIRST BENDING MODE

The first spacecraft flexible mode at 0.231 Hz is the solar array edgewise mode. The edgewise mode is due to flexibility in the yoke with the solar array moving as a rigid body in the in-plane direction.



S/A FIRST BENDING MODE

EDGEWISE MODE
FREQ = 0.232 HZ



SOLAR ARRAY SECOND BENDING MODE

The second spacecraft flexible mode at 0.249 Hz is the solar array flatwise mode. The flatwise mode consists primarily of bending in the solar array panels and hinges.

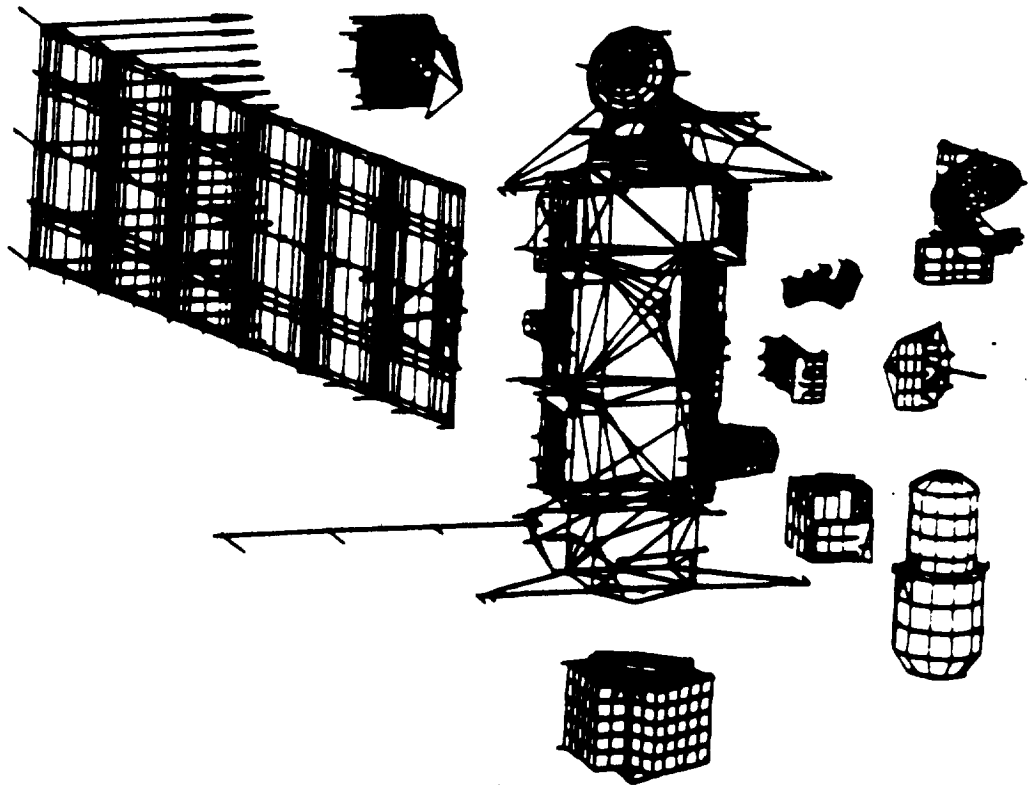


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S/A SECOND BENDING MODE

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FLATWISE MODE
FREQ = 0.262 HZ



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ANALYTICAL FREQUENCY PREDICTION VERSUS SOLAR ARRAY POSITION

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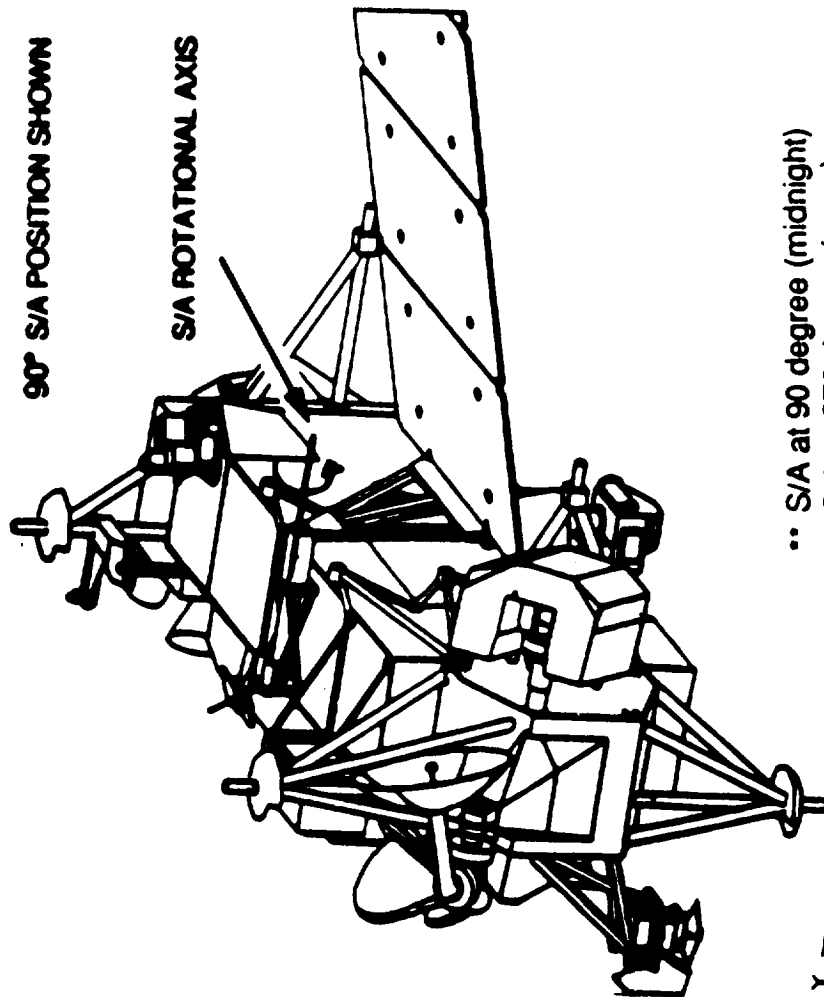
FREQUENCY VERSUS SOLAR ARRAY POSITION

Analytically, the flatwise and edgewise frequencies change with solar array position. Frequencies change because the modes act about different inertial axes. At the 90 degree solar array position (position illustrated in the chart below), the flatwise mode acts about the roll axis while the edgewise mode acts about the yaw axis. However if the solar array is rotated (about pitch) to the 180 degree position, the flatwise and edgewise mode switch inertial axes. The flatwise mode acts about yaw and the edgewise mode acts about roll.

Since the yaw inertia is approximately three times that of roll, a mode acting about yaw is more constrained than acting about roll. In the more constrained yaw position, the mode behaves more like a cantilevered mode than in the less constrained roll position, where its behavior tends toward a free-free condition. A structure in a cantilevered state has a lower natural frequency than in free-free state. Therefore, flatwise and edgewise modes have lower frequencies in yaw (cantilevered) than they do in roll (free-free).



FREQUENCY VERSUS S/A POSITION



.. S/A at 90 degree (midnight)
S/A at 270 degree (noon)
S/A at 30 degree (sunset)
S/A at 150 degree (sunrise)

Pitch - y
Roll - z
Yaw - x

FLATWISE MODE

<u>S/A POSITION</u>	<u>INERTIAL AXIS</u>	<u>MODE BEHAVIOR</u>
90°	Roll	Free-Free
180°	Yaw	Cantilevered

EDGEWISE MODE

<u>S/A POSITION</u>	<u>INERTIAL AXIS</u>	<u>MODE BEHAVIOR</u>
90°	Yaw	Cantilevered
180°	Roll	Free-Free

YAW INERTIA > ROLL INERTIA

Frequency Free-Free Mode > Frequency Cantilevered Mode

SOLAR ARRAY AT VARIOUS ANGLES

Solar array position is illustrated every 90 degrees. The solar array makes one complete rotation every orbit with one orbit lasting approximately 96 minutes. The sunrise position is at 150 degrees, noon is at 270 degrees, sunset is at 30 degrees, and midnight is at 90 degrees.

For 45 days after the June 1, 1992 solar array drive shutdown, the solar array was stationed near the noon position at 278 degrees.

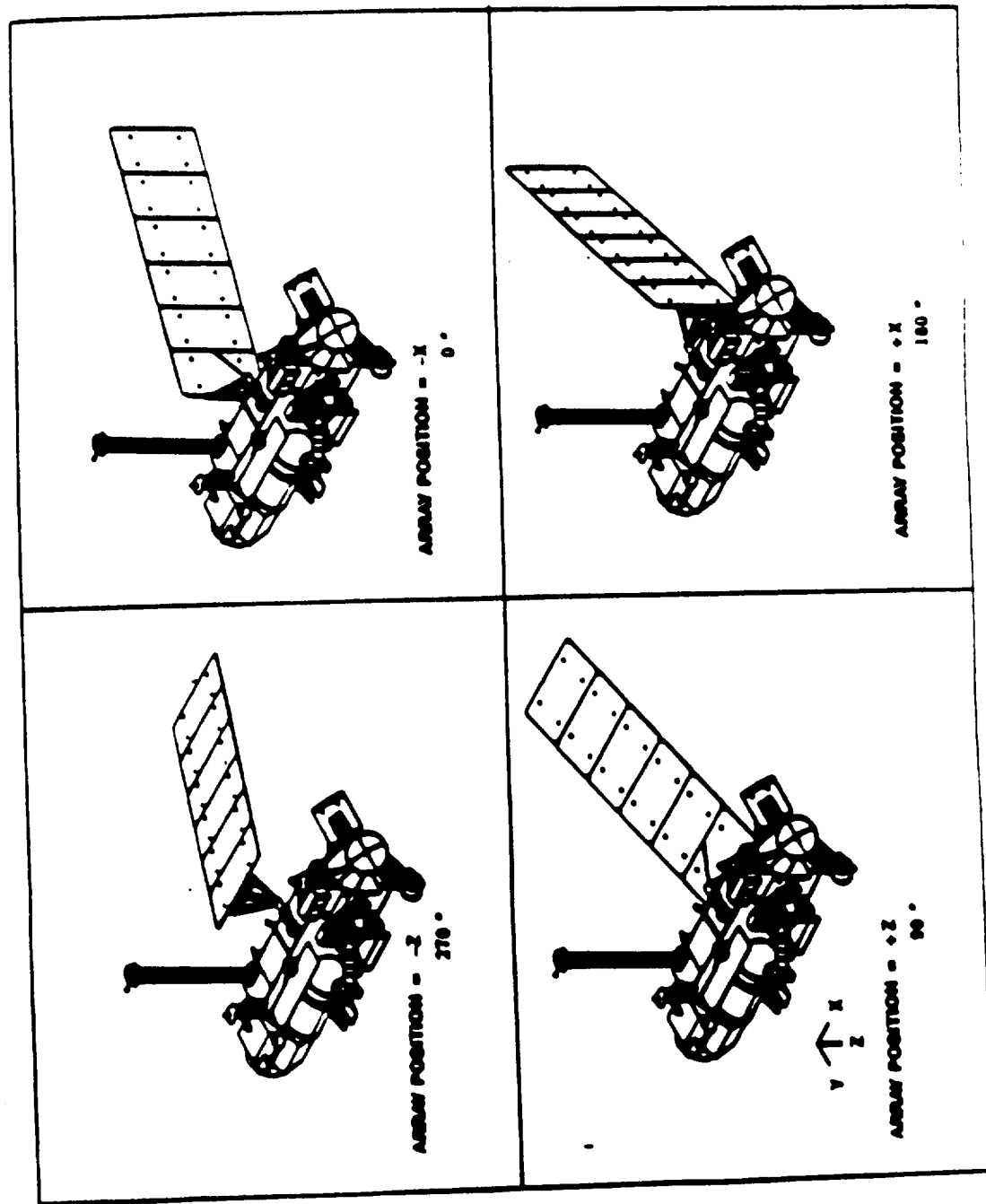


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GE Astro Space

Solar Array at Various Angles



ANALYTICAL FREQUENCIES FOR VARIOUS SOLAR ARRAY POSITIONS

The solar array flatwise and edgewise frequencies change by approximately 25% from the 90 to 180 degree position. Higher order modes, however, do not change considerably for different solar array positions.

FEM Frequency Prediction of Uars Spacecraft
for Different Solar Array Angles

Mode No.	45°	90°	135°	180°	Description
1-6	0	0	0	0	RIGID BODY MODES
7	0.222	0.262 *	0.221	0.213	S/A 1ST FLATWISE BENDING
8	0.278	0.232 *	0.279	0.288	S/A 1ST EDGEWISE BENDING
9	0.716	0.716	0.717	0.718	S/A 1ST TORSION IN Y
10	0.794	0.794	0.794	0.794	ZEPS BOOM 1ST BENDING IN X
11	0.851	0.844	0.850	0.855	ZEPS BOOM 1ST BENDING IN Y
12	1.13	1.15	1.15	1.14	S/A 2ND FLATWISE BENDING
13	1.18	1.18	1.18	1.18	S/A SUPPORT TUBES
14	1.70	1.70	1.70	1.70	SSPP ROTATION ABOUT Y (ALPHA)
15	1.82	1.82	1.82	1.82	SSPP ROTATION ABOUT X (BETA)
16	2.09	2.07	2.11	2.16	S/A 3RD FLATWISE BENDING
17	2.35	2.35	2.35	2.35	ZEPS 1ST TORSION ABOUT Z
18	2.67	2.67	2.67	2.67	S/A 2ND TORSION ABOUT Y
19	3.50	3.50	3.50	3.50	HRDI TEL TORSION ABOUT Z (AZIMUTH)
20	3.56	3.56	3.56	3.56	HRDI TEL TORSION ABOUT Y (ZENITH)

* mode switched

S/A at 90° (midnight)
S/A at 270° (noon)
S/A at 30° (sunset)
S/A at 150° (sunrise)

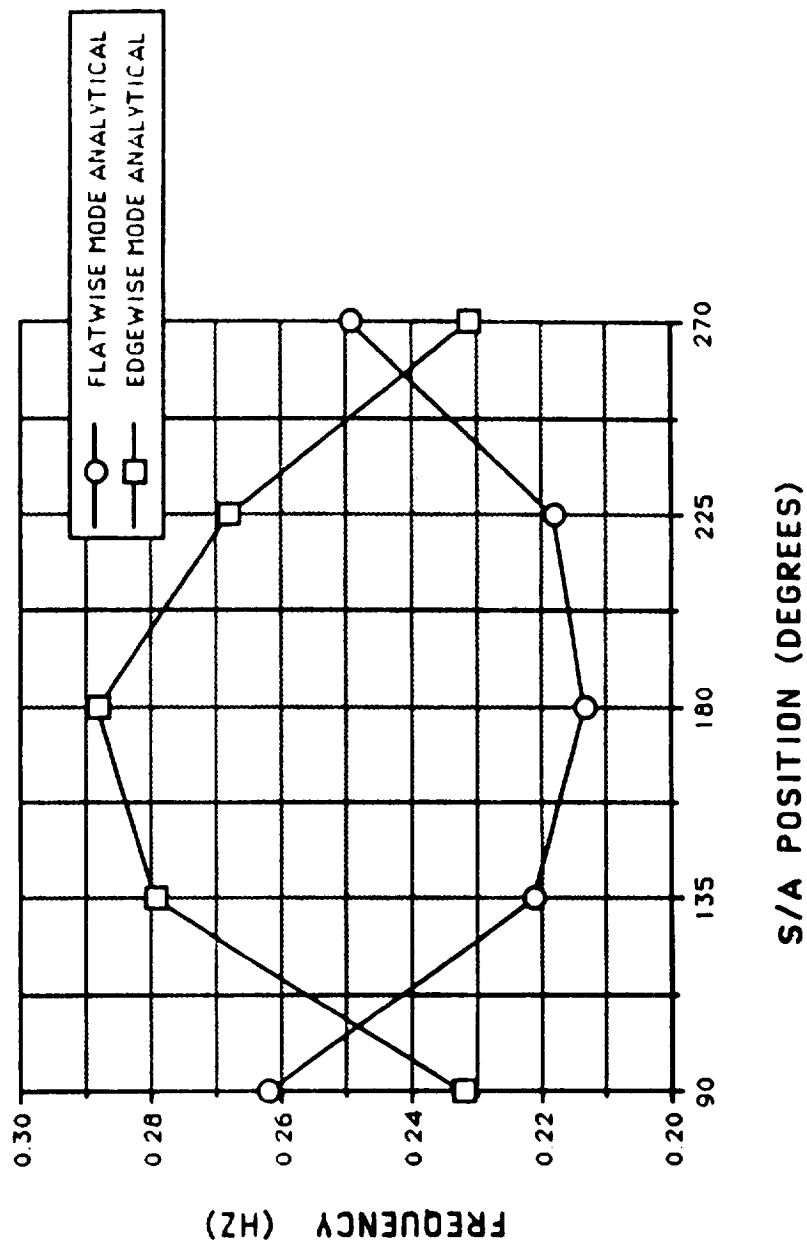
SOLAR ARRAY FREQUENCY VERSUS SOLAR ARRAY POSITION

The solar array flatwise and edgewise frequencies are plotted as a function of solar array position. When the solar array is rotated from 90 towards 180 degrees, the flatwise mode decreases in frequency since the inertial axis changes from roll to yaw. Conversely, the edgewise mode increases in frequency since its inertial axis changes from yaw to roll. As the solar array is rotated beyond 180 degrees (towards 270 degrees), the inertial axes revert back to that of the 90 degree position. There is a small difference in frequency between the 90 and 270 degree position because the solar array center of gravity is offset from its rotational axis.



S/A FREQUENCY VERSUS S/A POSITION

ANALYTICAL PREDICTIONS



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FREQUENCY AND DAMPING DETERMINATION USING "ERA" ROUTINE

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SYSTEM IDENTIFICATION

The Eigensystem Realization Algorithm (ERA) was developed jointly by Richard Pappa and Dr. Jer-Nan Juang of NASA Langley to do modal parameter identification using time history data. Frequency and modal damping values were obtained with ERA from response data measured from gyros on board the spacecraft.

The gyros, located within the Modular Attitude Control System (MACS), measure the rate of rotation in the spacecraft roll, pitch, and yaw axes. "High rate" gyro data is normally analyzed to determine which time periods constitute interesting data spans. "High rate" data averages the response over 1 second into counts where 1 count equals 0.39 arcseconds. For this analysis, "low rate" gyro data was analyzed to get a more precise look at the data. "Low rate" gyro data is sampled every 0.128 seconds (7.81 Hz sampling rate) in counts where 1 count equals 0.05 arcseconds. Each gyro is a 2 Hz device with a -12 dB/octave rolloff and has a maximum dynamic range of 255 counts. The "low rate" gyros are the most sensitive motion transducers on board UARS for application to this study.

The consistency of the ERA calculated modal parameters was determined from the Consistent Mode Indicator (CMI) function. Consistency is considered to be a reliable indicator of accuracy. CMI is on a scale from 0 to 1 with 1 being perfect. Modes with CMI greater than 0.80 are identified with high confidence while modes having values ranging from 0.80 down to 0 display moderate to large uncertainty. Fictitious "computational modes" have CMI values of zero.

There were two objectives from the ERA study. First, to measure UARS orbital frequencies at various solar array positions. Day 128 (January 17, 1992) gyro data was analyzed for frequency content using time windows in which the solar array was at various positions. Day 128 was a "typical" day for UARS in which the solar array drive and instruments were all operating nominally. Since the data is not free decay and all the forcing functions are unknown, reliable damping values cannot be measured from the data. An FFT analysis was performed on the same data to verify the frequencies obtained with ERA.

The second objective of ERA was to measure accurate modal damping values. Three sets of free decay gyro data were analyzed: roll gyro after Day 265 (June 2, 1992) solar array shutdown, yaw gyro after Day 265 solar array shutdown, and roll gyro after Day 301 (July 8, 1992) MLS shutdown.



SYSTEM IDENTIFICATION

Eigensystem Realization Algorithm "ERA"

- ERA software developed at NASA Langley
- Frequency and Damping Identification
 - Assuming Free Decay Data
- Consistency of Structural Modal Parameters were verified primarily by the Consistency Mode Indicator Function (CMI)
 - 0 to 1 scale with 1 being perfect
 - CMI > 0.8 "good mode"
- Measured system frequencies at various S/A positions
 - Day 128 (Jan 17, 1992) Roll, Pitch, and Yaw gyro data at various S/A positions
 - S/A Drive and all instruments on (not free decay data)
 - Measure system frequencies only (no damping since not free decay data)
 - Verified frequencies with FFT analysis
- Measured frequencies and damping values using free decay data
 - Day 265 (June 2, 1992) Roll Gyro after S/A shutdown
 - Day 265 (June 2, 1992) Yaw Gyro after S/A shutdown
 - Day 301 (July 8, 1992) Roll Gyro after MLS shutdown (S/A drive off)

FLIGHT FREQUENCIES AT VARIOUS SOLAR ARRAY POSITIONS

Day 128 (January 17, 1992) gyro data was analyzed for frequency content using ERA. Different time windows were analyzed to get measured flight frequencies as a function of solar array position. Time windows were 1.6 minutes in duration and the solar array rotates approximately 6 degrees in this time.

Results for the roll, pitch, and yaw gyros are presented in the next two charts. The greatest number of modes was detected with the roll gyro. This was expected since the roll inertia is approximately 1/3 that of either pitch or yaw.

The measured fundamental mode of the spacecraft was approximately 0.24 Hz. The 0.24 Hz mode, which did not change significantly in frequency with solar array position, is believed to be the solar array flatwise mode since it was detected at every solar array position. The solar array C.G. is offset from the solar array rotational axis in the direction orthogonal to the plane of the panel. Any motion of the solar array, due to the C.G. offset, will tend to excite the flatwise mode regardless of solar array position. The edgewise mode, which is not excited by the C.G. offset, is believed to be the second spacecraft mode (0.29 Hz) since it is only detected near 0 and 180 degrees, i.e., when the mode acts about the roll axis.

Other spacecraft modes detected by ERA with a CMI greater than 0.80 were at 0.95 Hz, 1.0 Hz, 2.15 Hz, and 2.9 Hz. All modes were dominant in roll except the 2.9 Hz mode which was dominant in yaw.

Other spacecraft modes were indicated but the CMI for each was less than 0.80. A low CMI does not necessarily indicate a lack of confidence in the calculated modal frequency but may be due to an inconsistency in the damping measurement. Energy of unknown proportion is being added to the modes due to the solar array drive and instrument disturbances. This will affect the apparent consistency of the damping measurement. Since CMI is affected by both frequency and damping (slightly more by damping consistency according to Richard Pappa), a structural frequency may have a CMI lower than 0.80. Modes with CMI greater than 0.60 were considered "real" modes for this study.



"ERA" Analysis Day 128 Roll Gyro

0-6	9-15	45-51	90-96	135-141	180-186	225-231	270-276	315-321
0.243 *	0.239 **	0.239 **	0.238	0.242 *	0.236 **	0.242 **	0.235 *	0.236 **
----	0.284	----	----	----	0.290 **	----	----	----
0.488	0.488 *	0.486	0.489	0.491	0.483	0.452	0.451	0.494
0.723	0.714	0.714	----	0.720	0.719	0.740	0.752	0.723
0.950 **	0.948 **	0.961	0.943	----	0.949	0.950	0.958	0.949 **
1.050	1.011	0.994	1.032 *	0.982 **	0.984 **	----	1.034	1.010
1.465	1.458	1.458	1.476	1.470 *	1.474	1.462	1.465	1.468
2.151 **	2.150 *	2.159 *	2.064	2.148	2.151 *	2.152	2.132	2.146 **
2.935 *	2.923	2.927 *	2.932	2.928 *	2.929	2.928	2.930	2.927 *

** Reliable Mode with Consistent Mode Indicator (CMI) > 0.80

* Distinguished Mode with Consistent Mode Indicator (CMI) > 0.60

EDGEWISE BENDING MODE ONLY DISCERNABLE NEAR 0° and 180°

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UARS JITTER STUDY

FLIGHT FREQUENCIES AT VARIOUS S/A POSITIONS

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"ERA" Analysis Day 128 Pitch Gyro

0-6	9-15	45-51	90-96	135-141	180-186	225-231	270-276	315-321
0.246	0.242	0.242	0.241 *	---	0.243	---	0.246 *	---
---	0.295	---	---	---	---	---	---	---
---	0.430	---	0.485	---	---	---	---	---
---	0.724	0.720	---	---	---	---	---	---
---	0.948 **	0.969	---	---	---	---	---	---

"ERA" Analysis Day 128 Yaw Gyro

0-6	9-15	45-51	90-96	135-141	180-186	225-231	270-276	315-321
0.245 *	0.248	0.254	0.233	0.251	0.245	0.267	0.240 **	0.240
---	0.493	0.476	0.479 *	0.499	---	0.431	0.430	---
0.727	0.727	0.719	0.725	0.723	0.732 *	0.713	0.725	0.716
0.947 *	0.948 **	0.947	0.919	0.976	0.951	0.946	0.962	0.976
1.031	1.045	---	1.012	1.086	---	---	---	---
1.262	1.238	1.247	1.287	1.223	---	---	---	---
---	2.197	2.192	2.152	2.168	---	---	---	---
2.929 **	2.929 **	2.930 **	2.930 **	2.930 **	2.929 **	2.930 **	2.931 **	2.929 **

** Reliable Mode with Consistent Mode Indicator (CMI) > 0.80

* Distinguished Mode with Consistent Mode Indicator (CMI) > 0.60

ERA FREQUENCY ANALYSIS CORRELATION

It is not possible to categorically assign measured frequencies to either flatwise or edgewise solar array modes using the limited instrumentation available on UARS. The reason flight frequencies were identified as either flatwise or edgewise bending is discussed in chart 38 and is based solely on the data presented in this study.

The measured flight flatwise frequency did not fluctuate significantly with solar array position as analysis predicts but was relatively constant at 0.24 Hz. The edgewise frequency was 0.29 Hz near the 0 and 180 degree solar array positions. The flight measurements for the flatwise and edgewise modes both came within 10 percent of the predicted value.

Except for the 2.9 Hz flight mode, identification of the flight frequencies greater than 0.29 Hz is based strictly on matching flight frequencies to the nearest analytical frequency. The 2.9 Hz flight mode is believed to be the HRDI Telescope torsion about Z since the mode is most active in yaw. Based on the MLS PSD analysis presented later, the 0.48 Hz flight frequency is due to the frequency content of the ongoing MLS disturbance rather than a spacecraft structural mode.

Note that without gyros or another forms of instrumentation on the different instruments, there will always be some uncertainty in identifying modes.

**"ERA" FREQUENCY ANALYSIS CORRELATION****180° SOLAR ARRAY POSITION**

Mode Description	Analytical Predictions	Flight Frequency
S/A 1st Flatwise Bending	0.213	0.236
S/A 1st Edgewise Bending	0.288	0.290
	----	0.488
S/A 1st Torsion in Y	0.718	0.730
ZEPS Boom 1st Bending in X	0.794	
ZEPS Boom 1st Bending in Y	0.855	0.948
S/A 2nd Flatwise Bending	1.14	1.03
S/A Support Tubes	1.18	
SSPP Rotation about Y (Alpha)	1.70	
SSPP Rotation about X (Beta)	1.82	
S/A 3rd Flatwise Bending	2.16	2.15
ZEPS 1st Torsion about Z	2.35	
S/A 2nd Torsion about Y	2.67	
HRDI TEL Torsion about Z (AZIMUTH)	3.50	2.93
HRDI TEL Torsion about Y (ZENITH)	3.56	

FLIGHT DATA WITHIN 10 PERCENT OF ANALYTICAL
PREDICTION FOR FIRST TWO S/A MODES

FREQUENCY CORRELATION VERSUS SOLAR ARRAY ANGLE

Measured frequencies are compared to analytic for the solar array flatwise and edgewise modes. Except for two points, all the data plotted came from the Day 128 ERA analysis. The two additional data points for the edgewise mode came from PSD analysis. The Day 128 PSD analysis was performed by Stan Woodard of NASA Langley. The Day 301 PSD analysis is presented later in the MLS PSD Correlation section of this report.

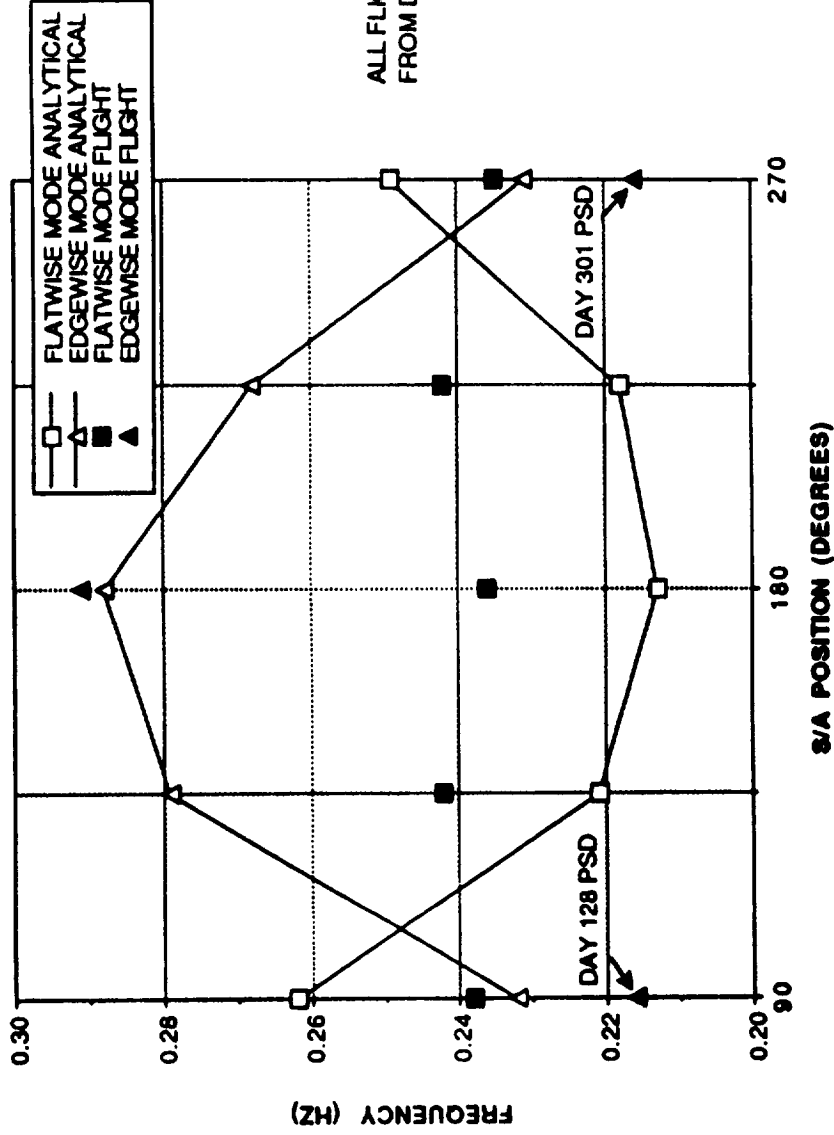
Results of the correlation indicate that the measured flight flatwise mode does not change with solar array position as the analysis predicts. However, the measured edgewise mode does follow the analytic trend of increasing in frequency from 90 to 180 degrees and then decreasing in frequency from 180 to 270 degrees. For both the flatwise and edgewise modes, the analytical predictions are within 10 percent of the measured flight data.



UARS JITTER STUDY

FREQUENCY CORRELATION VERSUS S/A ANGLE

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- FLIGHT FLATWISE FREQUENCY DOES NOT CHANGE WITH S/A ANGLE
- FLIGHT EDGEWISE FREQUENCY SHOWS EXCELLENT AGREEMENT WITH ANALYTIC FREQUENCY

ANALYTICAL PREDICTIONS WITHIN 10% OF FLIGHT MODES

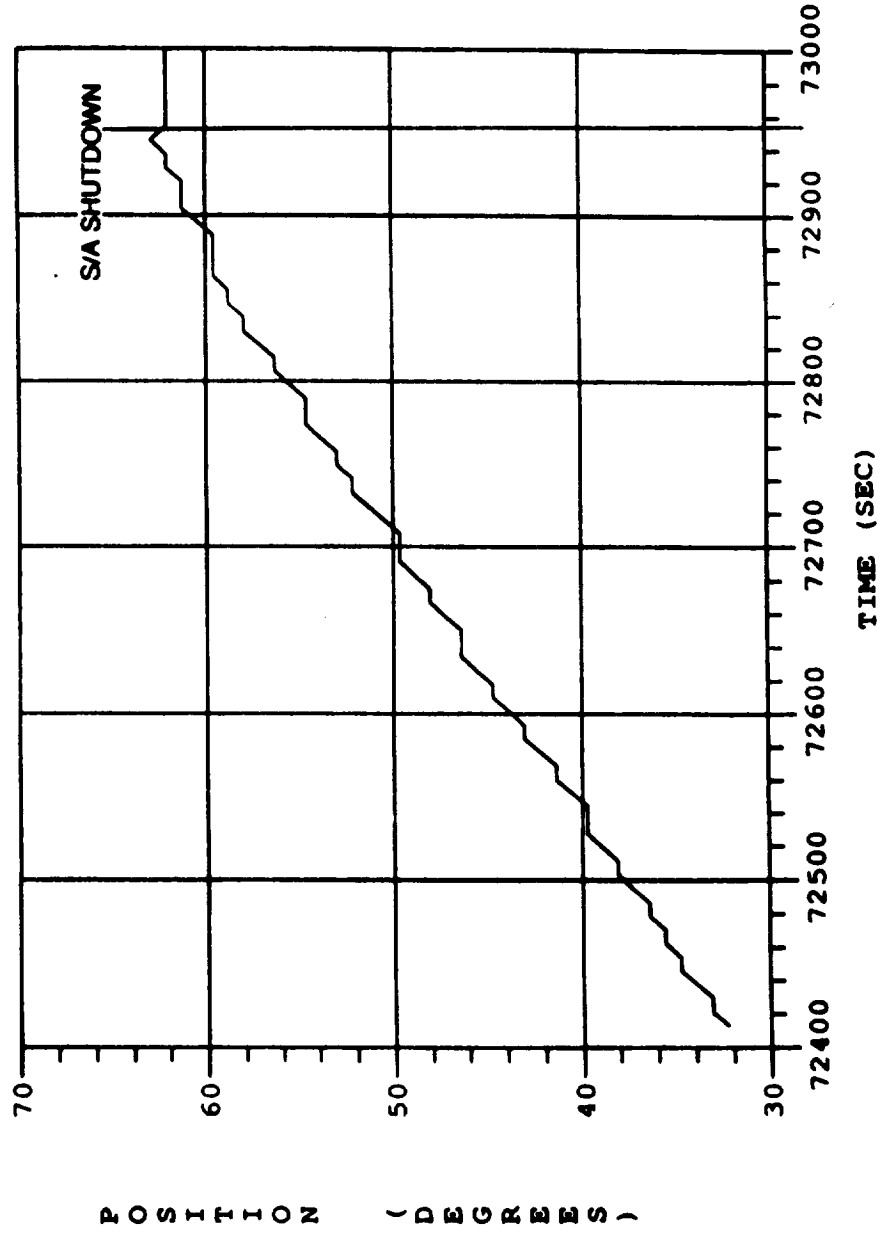
DAY 265 SOLAR ARRAY DRIVE SHUTDOWN

On Day 264 (June 1, 1992) there was an unplanned solar array drive shutdown. The shutdown is believed to be due to a problem with the clutch system in the drive mechanism. After completion of a yaw around maneuver, the solar array drive motor reverses its direction of rotation. The design of the clutch mechanism is such that there should be a delay between the time the drive motor reverses direction and when the solar array reverses direction. However, on Day 264, the reversal of the drive motor caused an immediate reversal of the solar array. Several minutes later the solar array stalled. The UARS control system monitored the anomaly and switched to the backup drive mechanism (the B drive). The B drive ran nominally for approximately 1 day until, on Day 265, the solar array stalled after a sunset thermal snap. After the stall, the drive mechanism was shut down and the solar array was parked at the noon position. Tests were done on both the A and B drives for more than 40 days until it was concluded that the A drive could effectively drive the system.

The solar array position for a 13 minute time period on Day 265 is shown in the chart. The x-axis represents the number of seconds into the day. The y-axis is the solar array position in degrees. At 72953 seconds, the solar array stops rotating. Telemetry is downlinked at a data rate of one sample every 8 UARS seconds (1 UARS second = 1.028 seconds) with a resolution of 0.83 degrees.



DAY 265 SOLAR ARRAY ENCODER POSITION



UNPLANNED SHUTDOWN OF B-DRIVE

ERA FREQUENCY AND DAMPING ANALYSIS (ROLL GYRO S/A SHUTDOWN DAY 265)

Roll gyro data for the time period immediately before and after the B drive shutdown on Day 265 is presented. The x-axis represents the number of seconds into the day. The y-axis is the raw gyro data, which is sampled every 0.128 seconds, multiplied by 0.05 which is the conversion from counts to arcseconds.

The 0.25 Hz mode dominates the response with a 1 arcsecond peak magnitude (20 counts) immediately after shutdown. A 1 Hz mode modulates the 0.25 Hz mode. Its peak magnitude is approximately 0.3 arcseconds (6 counts).

Modal damping values were determined immediately after the solar array shutdown using ERA. To determine the damping consistency throughout the decay, three different time periods were analyzed. Each time period was 10.4 seconds in duration which equates to 2.5 cycles of the 0.25 Hz mode. The second and third time periods were shifted over 4 seconds, or 1 complete cycle of the 0.25 Hz mode, from the previous time period. A fourth analysis, running from the beginning of time period 1 to the end of time period 3, was also performed to determine the average damping value throughout the decay.

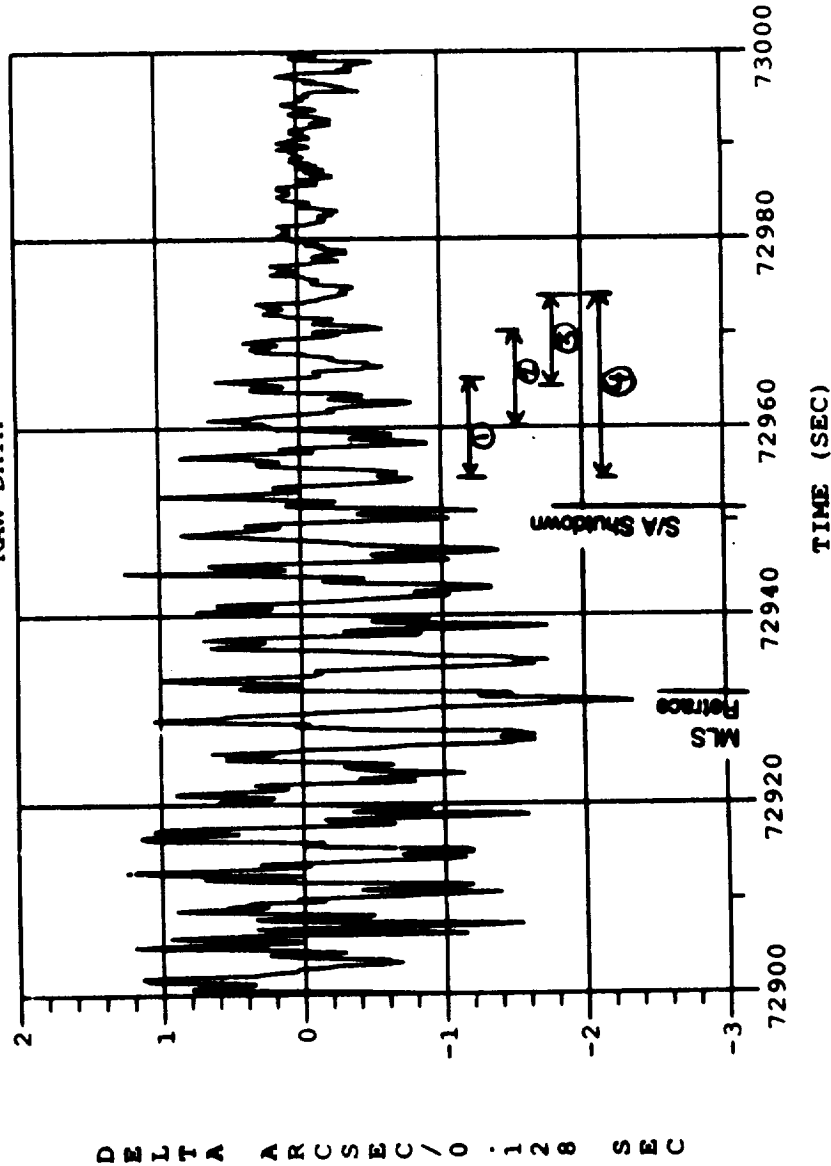


UARS JITTER STUDY

"ERA" FREQUENCY AND DAMPING ANALYSIS 49

ROLL GYRO S/A SHUTDOWN DAY 265

DAY 265	UARS ROLL GYRO ON ORBIT DATA	RAW DATA	INSTRUMENT	STATUS
			MLS	SCANNING
			HGA	REWIND
			SSPP	OFF
			HRDI	SCANNING
			HALOE	AZIM. TRACKING
				ELEV. FIXED



Telemetry Point OBSCNGX
1 count = 0.05 arcsec
Sampling time 0.128 sec

Analyzed 3 Time Periods each 10 Seconds in Duration to
Determine Consistency of Measured Damping Value

ERA RESULTS FOR SOLAR ARRAY SHUTDOWN ROLL GYRO

Results of the ERA analysis for the different time periods are presented. The first mode, believed to be flatwise bending, had consistent damping. For each time window, damping was approximately 2.8 % and the CMI exceeded 0.96.

Damping values for the higher order modes were not consistent. For each of the three smaller time windows, two modes at 0.98 Hz and 1.13 Hz were identified with CMI's greater than 0.80. Damping values fluctuated from 0.7 to 2.0 percent for the 0.98 Hz mode and from 0.1 to 1.1 percent for the 1.13 Hz mode. The 0.98 Hz and 1.13 Hz modes are believed to be the ZEPS bending and solar array second flatwise bending, respectively.

Damping values for these modes fluctuate because the gyro resolution is not small enough as compared to the magnitude of the disturbance. The peak magnitude of the 1 Hz response is only 0.3 arcseconds while the gyro resolution is 0.05 arcseconds (1/6 of the peak). A larger disturbance or finer gyro resolution is required to accurately measure damping for the higher order modes. The damping values calculated in the first time window (0.72% for 0.98 Hz and 0.51% for 1.13 Hz) are probably the most accurate since it has the largest disturbance.

Other modes with CMI values less than 0.80 are also shown. These frequencies indicate other spacecraft modes which are excited to only a small degree by the disturbance. Damping values calculated for these modes are inaccurate and should be ignored.



UARS JITTER STUDY

ERA RESULTS FOR S/A SHUTDOWN ROLL GYRO

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ANAL #	START TIME (SEC)	WINDOW (SEC)	FREQ (HZ)	DAMPING (%C/Cc)	CMI
#1	72956	10.4	0.252	2.93	.968 *
			0.494	0.08	.352
			0.973	0.72	.916 *
			1.13	0.51	.897 *
			1.44	0.10	.616
#2	72960	10.4	1.96	0.22	.504
			0.252	2.84	.961 *
			0.979	0.91	.956 *
			1.14	1.06	.891 *
#3	72964	10.4	2.93	-0.17	.646
			0.252	2.82	.978 *
			0.982	2.01	.854 *
			1.12	0.14	.836 *
#4	72956	18.6	2.93	-0.17	.740
			0.252	2.91	.973 *
			0.482	1.00	.438
			0.975	1.37	.544
			1.13	0.66	.798
			1.95	0.66	.783
			2.93	-0.11	.956 *

* CMI > 0.80

DAMPING VALUE FOR FIRST MODE
CONSTANT OVER EACH WINDOW

ERA FREQUENCY AND DAMPING ANALYSIS (YAW GYRO S/A SHUTDOWN DAY 265)

Yaw gyro data for the time period immediately before and after the B drive shutdown on Day 265 is presented. The x-axis represents the number of seconds into the day. The y-axis is the raw gyro data multiplied by 0.05 which is the conversion from counts to arcseconds.

The 0.25 Hz mode dominates the response with a 0.30 arcsecond peak magnitude (6 counts) immediately after shutdown. Higher frequency modes with a peak magnitude of 0.1 arcsecond (2 counts) modulate the 0.25 Hz mode.

Two time periods (numbers 1 and 2) after the shutdown were analyzed. The two time periods are each 10.4 seconds in duration and correspond to the first two time periods in the roll gyro analysis. Three time periods before the solar array came completely to rest and after the MLS retrace were also analyzed (numbers 3,4, and 5).



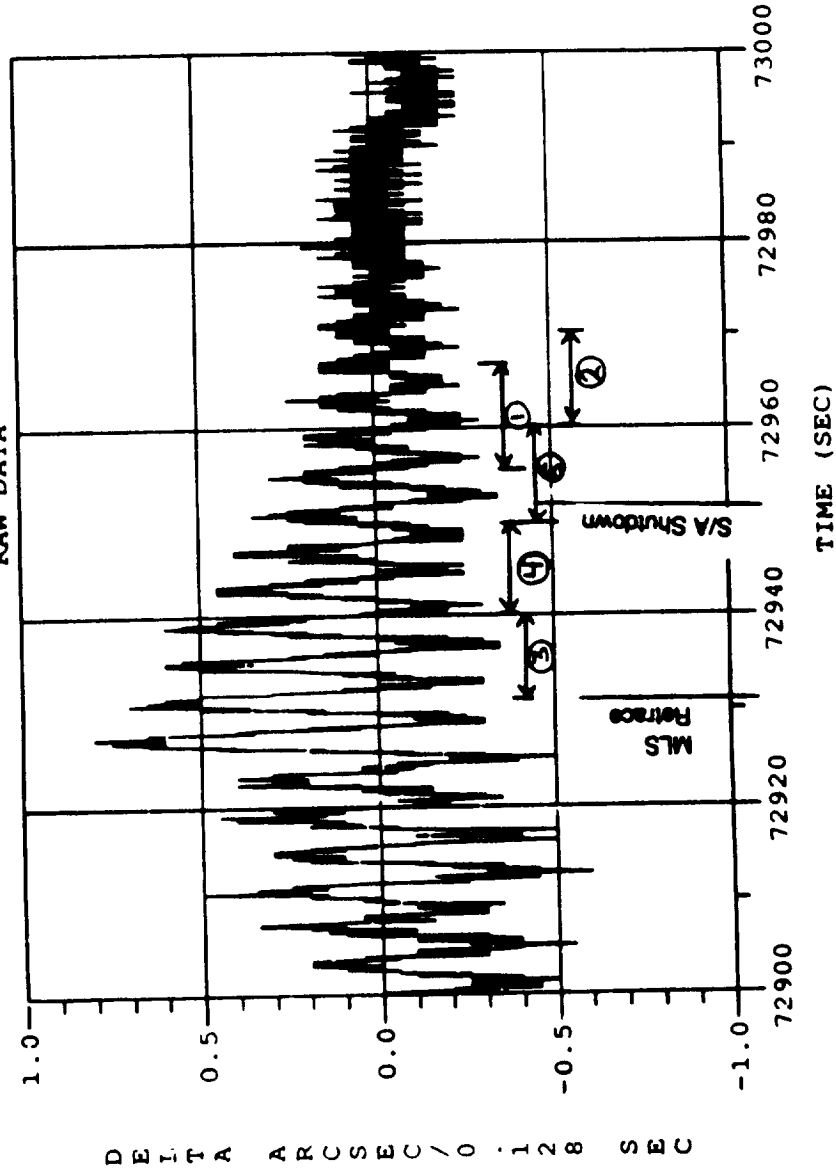
UARS JITTER STUDY

"ERA" FREQUENCY AND DAMPING ANALYSIS 53

YAW GYRO S/A SHUTDOWN DAY 265

DAY 265 UARS YAW GYRO ON ORBIT DATA

RAW DATA



INSTRUMENT

MLS
HGA
SSPP
HRDI
HALOE

STATUS

SCANNING
REWIND
OFF
SCANNING
AZIM. TRACKING
ELEV. FIXED

Telemetry Point OBSCNGZ

1 count = 0.05 arcsec

Sampling time 0.128 sec

MAXIMUM PEAK 0.3 ARCSEC (6 COUNTS)

ERA RESULTS FOR SOLAR ARRAY SHUTDOWN YAW GYRO

Results of the ERA analysis for the different time periods are presented. The disturbance magnitude was not large enough, as compared to the resolution of the gyro, to get a consistent (i.e. accurate) measure of damping. After the solar array drive shutdown, first mode damping ranged from 1.7 to 3.8 percent, while before the shutdown, damping ranged from 0.1 to 4.5 percent.

A 2.93 Hz mode was measured in each time window. The mode, with a CMI greater than 0.80 in 4 of the 5 windows, had a very small or even negative damping value. A negative damping value indicates that energy is being added to the mode from some outside disturbance. The 2.93 Hz mode is believed to be the HRDI Z torsion since it is most active in yaw.



UARS JITTER STUDY

ERA RESULTS FOR S/A SHUTDOWN YAW GYRO

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ANAL #	START TIME (SEC)	WINDOW (SEC)	FREQ (HZ)	DAMPING (%C/Cc)	CMI
#1	72956	10.4	0.247	1.72	.892 *
			2.93	-0.02	.910 *
#2	72960	10.4	0.253	3.78	.928 *
			2.93	-0.002	.654
#3	72930	10.4	0.256	0.12	.900 *
			1.13	-1.38	.778
			2.93	-0.16	.946 *
#4	72940	10.4	0.254	2.74	.944 *
			1.13	-0.40	.774
			2.93	-0.09	.862 *
#5	72950	10.4	0.253	4.45	.880 *
			2.93	0.11	.902 *

* CMI > 0.80

INSUFFICIENT DISTURBANCE TO OBTAIN
ACCURATE DAMPING VALUE

ERA FREQUENCY AND DAMPING ANALYSIS (ROLL GYRO MLS SHUTDOWN DAY 301)

Roll gyro data for a 40 second time period covering the MLS shutdown on Day 301 is presented. The x-axis represents the number of seconds into the day. The y-axis is the raw gyro data multiplied by 0.05 which is the conversion from counts to arcseconds.

The MLS antenna is tracking until time 45276 seconds when it stops. Three seconds later at time 45279 seconds it begins its retrace which lasts until time 45282.5 seconds when the MLS shuts down. The peak gyro response after shutdown is only 0.20 arcseconds (4 counts). The magnitude was insufficient to obtain accurate damping values and no ERA analysis was performed.

After the MLS shutdown, the ambient level due to the HGA tracking and reaction wheels running at nominal rate is seen. There exists a 0.25 Hz response with a peak rate of 0.1 arcseconds per 0.128 seconds.

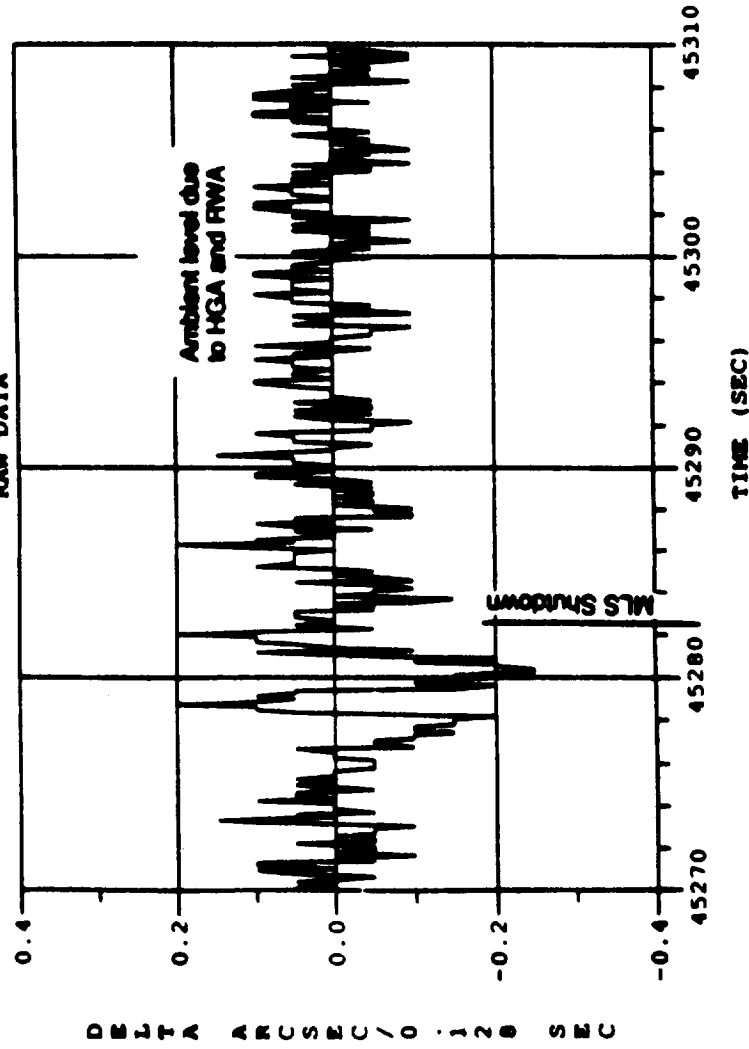


UARS JITTER STUDY

"ERA" FREQUENCY AND DAMPING ANALYSIS 57

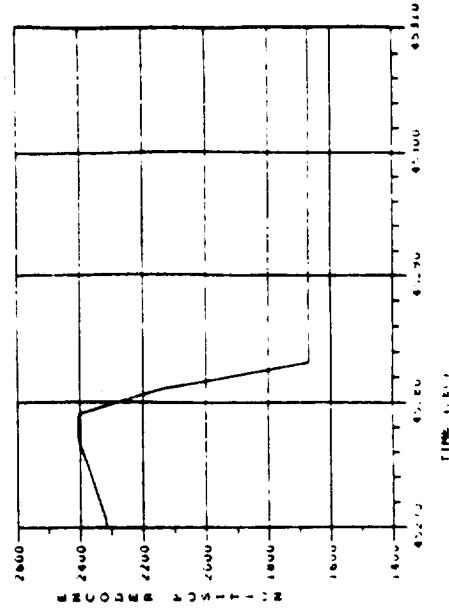
ROLL GYRO MLS SHUTDOWN DAY 301

DAY 301 UARS ROLL GYRO ON ORBIT DATA
RAW DATA



Telemetry Point OBSCNGX 1 count = 0.05 arcsec
Sampling time 0.128 sec

DAY 301 MLS ANTENNA ENCODER POSITION



INSTRUMENT

S/A

HGA
ALL OTHER

STATUS

SHUTDOWN
(278° POSN)

TRACKING
OFF

Maximum Peak is only 0.2 arcsec (4 counts)
Insufficient to Obtain Accurate Damping Values

ERA ANALYSIS SUMMARY

Flight frequencies were measured at different solar positions using Day 128 roll, pitch, and yaw gyro data. The solar array flatwise mode was measured at each solar array position while the edgewise mode could only be detected when it acted about spacecraft roll near the 0 and 180 degree positions.

Only the response in roll after the solar array shutdown was sufficient to get an accurate measure of damping for the fundamental mode. Both the response in yaw after the solar array shutdown and the response in roll after the MLS shutdown were not large enough as compared to the gyro resolution to accurately measure damping.

Using the roll gyro data after solar array shutdown, a consistent damping value of 2.8 percent was measured for the flatwise bending mode. Damping for the 0.98 Hz and 1.13 Hz modes were measured to be 0.7% and 0.5%, respectively. Less confidence is placed in these damping measurements since the magnitude of the 1 Hz response was much smaller and gyro resolution became a problem. No damping estimates for higher order modes were obtained due to the limited gyro resolution.

Edgewise damping could not be obtained because the mode is not sufficiently excited at the 60 degree (during solar array shutdown) and 278 degree (during MLS shutdown) position. For the best chance of measuring edgewise damping, a large disturbance would be required with the solar array at the 0 or 180 degree position.



From Frequency Versus S/A Position Analysis (DAY 128 Gyro Data)

- 1st flatwise S/A mode can be detected at each S/A position
- 1st edgewise S/A mode can be detected near 0° and 180° only

From Damping Analysis (Day 265 and 301 Gyro Data)

- Large disturbance (~1 ARCSEC/0.128 SEC) required to obtain accurate damping values with current resolution on Gyros
 - Achieved consistent damping value of 2.8% for flatwise bending mode
 - Best damping measurement for 0.98 Hz and 1.13 Hz modes is 0.7% and 0.5% respectively
 - Insufficient magnitude in response for calculating accurate damping value for higher order modes
- Because edgewise mode is not excited at 62° S/A position (position during shutdown), edgewise damping value could not be obtained

DAMPING COMPARISON

Damping measured on UARS is compared to that measured on board DMSP and LANDSAT. NOAA is the civil version of the Air Force owned DMSP spacecraft and, thus, the two spacecraft are extremely similar in design. UARS and DMSP have similar damping values. LANDSAT has lower damping but it increases with the level of disturbance.

The difference in spacecraft damping cannot be explained by comparing solar array designs. DMSP has a much different solar array design from either LANDSAT or UARS which have quite similar designs. UARS has six solar panels in which the last three are unlatched. LANDSAT, which has slightly smaller panels than UARS, has only 4 panels which have no panel to panel latches. The major difference in the solar array design is in the yoke. LANDSAT's yoke is much shorter and stiffer than that of UARS. UARS also has an extra strut support between the panel 1/panel 2 hinge line and the yoke hinge. However, both the UARS and LANDSAT mode shapes indicate bending is occurring in the panels with very little if any involvement at the yoke.

DMSP and NOAA, however, have a much different design than either UARS or LANDSAT. The major design feature that could affect modal damping are rotary dampers used to slow the rate of deployment. Bending in the solar panels will induce rotation in the hinges, thus increasing damping.

UARS high damping level as compared to LANDSAT may be due to a higher level of disturbance. Integrating the UARS rate gyro data yields a 10 arcsecond peak disturbance after the solar array drive shutdown. The peak disturbance for the LANDSAT Thematic Mapper (TM) and Multi Spectral Scanner (MSS) shutdowns are 2.5 to 10 times smaller. Since it is generally acknowledged that damping increases with the level of disturbance (as seen by LANDSAT), it is plausible the UARS high damping measurement could be due to the comparatively large 10 arcsecond disturbance.



DAMPING COMPARISON

	DISTURBANCE	DISTURB. MAGNITUDE	FREQ (HZ)	DAMPING (%C/Cc)	PANEL STRUCTURE
UARS	SAD SHUTDOWN	10 ARCSEC	0.25	2.8	6 panels hinged, alum H/C last 3 panels unlatched
DMSP NOAA	THRUSTERS FIRED THRUSTERS FIRED		0.6	3.0 3.0	10 panels hinged, alum H/C rotary dampers at hinges
LS/D 4 LS/D 5 LS/D 5	MSS SHUTDOWN MSS SHUTDOWN TM SHUTDOWN	1 ARCSEC 1 ARCSEC 4 ARCSEC	0.4	0.4 0.2 1.3	4 panels hinged, alum H/C no panel to panel latches

- LARGE DMSP DAMPING POSSIBLY DUE TO ROTARY DAMPERS IN HINGES
- LANDSAT DAMPING INCREASES WITH THE LEVEL OF DISTURBANCE
- LANDSAT AND UARS PANELS ARE SIMILAR IN DESIGN
- LANDSAT YOKE MUCH SHORTER AND STIFFER THAN UARS
- LANDSAT AND UARS S/A MODE HAVE SIMILAR MODE SHAPES

UARS LARGER DAMPING AS COMPARED TO LANDSAT
COULD BE DUE TO A GREATER DISTURBANCE

SURVEY OF SPACECRAFT DAMPING VALUES

Dr. Stepan Simonian of TRW Space and Technology Group compiled a list of measured damping values for spacecraft structures. The information was intended for in-orbit applications since only damping data under low amplitude vibrations was collected. The list included the results of spacecraft ground modal survey tests (sine dwell) as well as published data on in-orbit damping measurements. Excluded from the list was damping data measured under high amplitudes since jitter is characterized by low amplitude vibration.

A scatter plot of the collected data is shown in the chart along with the measured UARS modal damping value. UARS damping is about average for its frequency range although few data points exist. In order to be conservative, the UARS pre-launch jitter analysis assumed 0.2% modal damping for all modes.



SURVEY OF SPACECRAFT DAMPING VALUES



ASSUMED 0.2% MODAL DAMPING FOR UARS PRE-LAUNCH JITTER ANALYSIS

JITTER DUE TO SOLAR ARRAY DRIVE

Jitter created by the solar array drive disturbance is discussed. Unknown before launch, the solar array drive is the primary disturbance on board the spacecraft. All jitter correlation studies due to the different instruments must be made when the solar array drive is off.



JITTER DUE TO SOLAR ARRAY DRIVE

MAY 1 DISTURBANCE EXPERIMENT

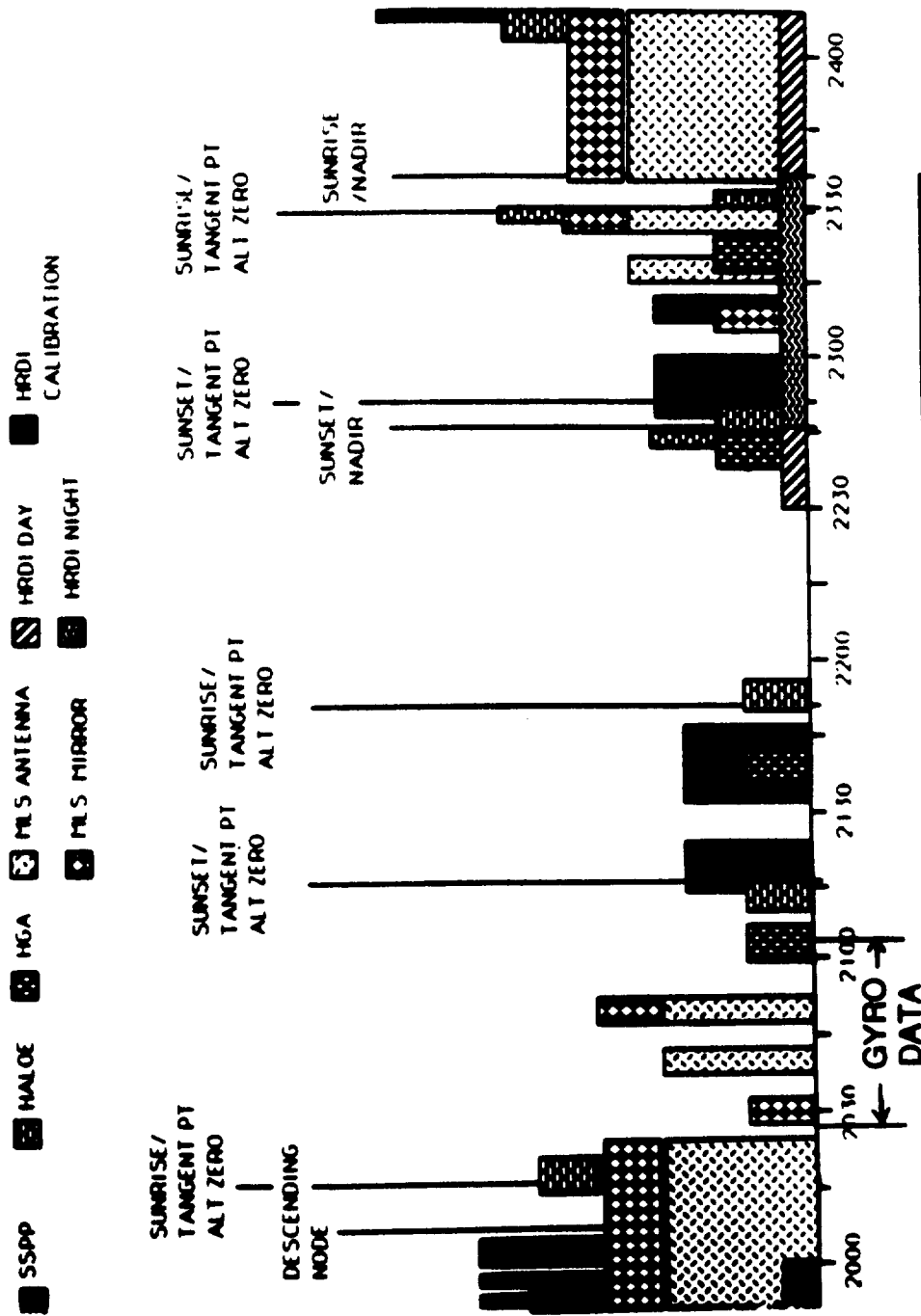
On May 1, 1992, an in-flight jitter experiment was performed for the Langley Research Center. The purpose of the experiment was to isolate some of the different jitter sources in order to characterize each response. The solar array drive was operating nominally at this time.

Gyro data for a 2500 second time period covering the MLS antenna and switching mirror events will be shown in the following chart. This portion of the May 1 test isolates the MLS switching mirror and antenna disturbances each for five EMAFs (engineering major frame - approximately 65 seconds) before both the mirror and antenna scan sequences occur simultaneously for five more EMAFs. The MLS remains quiet for five EMAFs between each event.



MAY 1 DISTURBANCE EXPERIMENT

UARS DISTURBANCE EXPERIMENTS DURING MAY 1 YAW AROUND



DIFFERENT JITTER SOURCES ISOLATED

ROLL GYRO MAY 1 DISTURBANCE EXPERIMENT

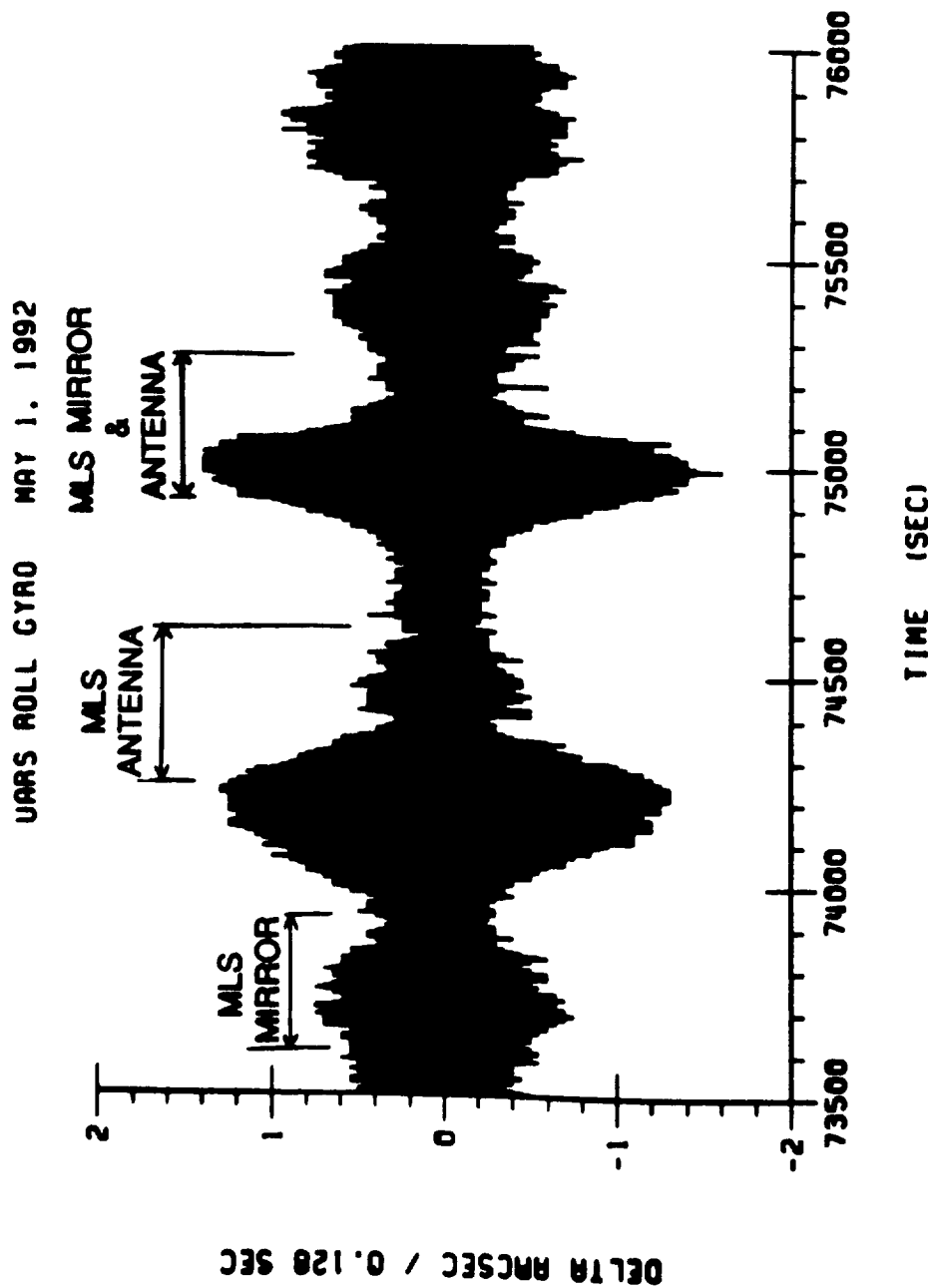
Roll gyro data for a 2500 second time period covering the MLS antenna and switching mirror events is presented. The x-axis represents the number of seconds into the day. The y-axis is the raw gyro data multiplied by 0.05 which is the conversion from counts to arcseconds.

The spacecraft response due to the MLS antenna and switching mirror events cannot be seen. The response is being masked by jitter with a five minute periodicity present only when the solar array drive is on.



UARS JITTER STUDY

ROLL GYRO MAY 1 DISTURBANCE EXPERIMENT 69



"BEATING" PHENOMENON APPARENT IN DATA
OVERWHELMS JITTER DUE TO DIFFERENT INSTRUMENTS

SOLAR ARRAY DRIVE JITTER SOURCE

The cause of the beating phenomenon was originally unknown but the solar array drive or reaction wheels were suspected. After the solar array drive anomaly on June 1, 1992 in which the solar array stopped rotating, the beating phenomenon disappeared and jitter was reduced to near zero.

Both intensive lab work as well as analytical modeling was performed to determine why the solar array stopped rotating. A by-product of this work was the discovery that the harmonic drive is the root cause of the beating phenomenon. It acts as a sinusoidal forcing function at 0.23 Hz, exciting the solar array modes near 0.25 Hz, creating the greatest spacecraft jitter.



SAD JITTER SOURCE

- Larger than expected jitter (6 arcsec/sec) observed during normal operation
 - Reason/cause originally unknown - Solar array drive (SAD) and/or reaction wheels suspected
 - Vibration appears in bursts - an apparent frequency "beating" phenomenon
- SAD Anomaly
 - Solar array stopped rotating during Yaw-Around #8 (June 1, 1992)
 - Spacecraft jitter reduced to near zero
 - Intensive investigation started including:
 - Lab tests of SAD engineering models at GE ASTRO Valley Forge
 - Dynamic modeling and flight data analysis
- Jitter source traced to characteristics of harmonic drive in SAD. Jitter not necessarily related to anomaly.
 - Harmonic drive acts as sinusoidal forcing function (0.23 Hz)
 - S/A modes (~0.25 Hz) excited resulting in spacecraft jitter

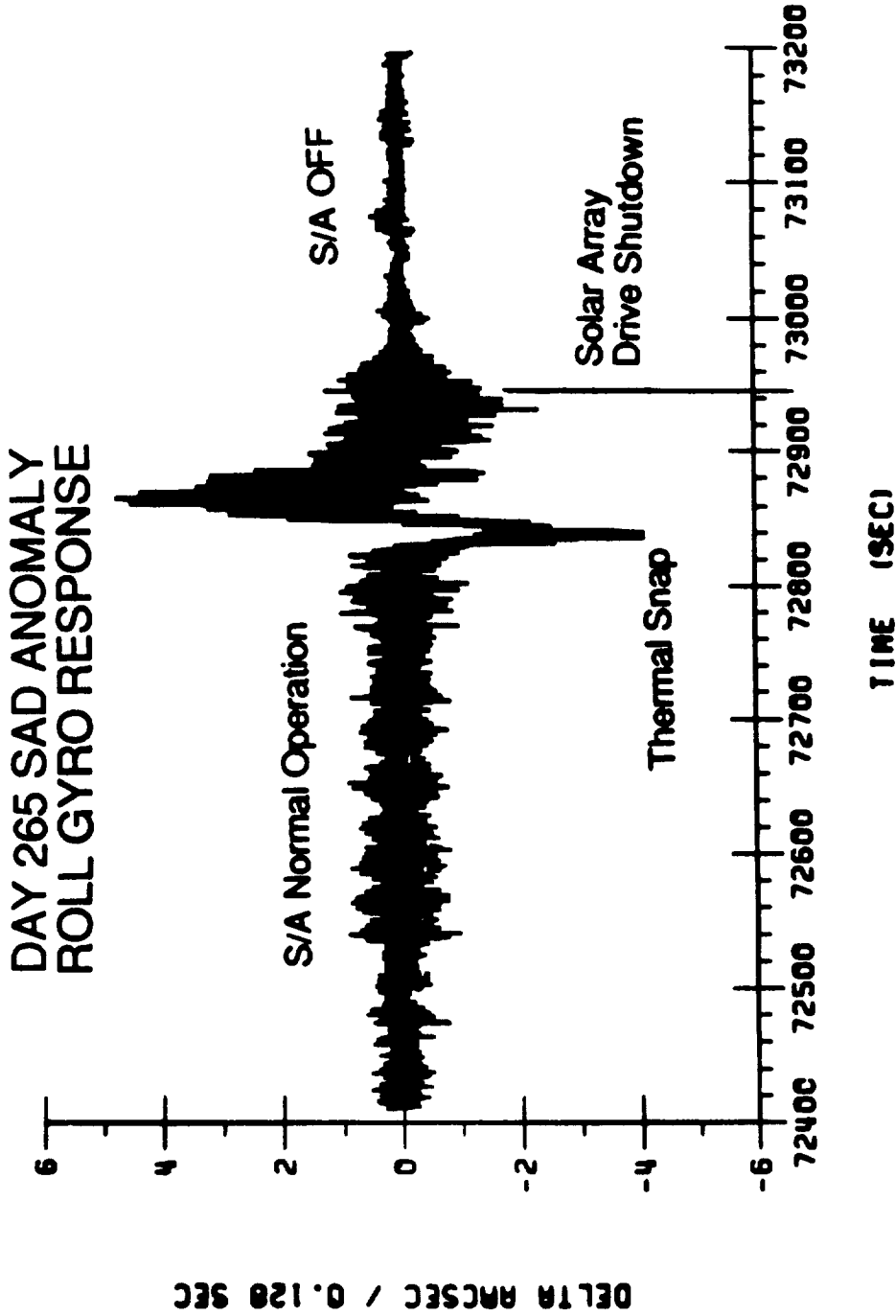
JITTER CONTRIBUTION FROM SOLAR ARRAY DRIVE

Roll gyro data for a 800 second time period before and after the B drive shutdown on Day 265 is presented. The x-axis represents the number of seconds into the day. The y-axis is the raw gyro data multiplied by 0.05 which is the conversion from counts to arcseconds. After the solar array drive is shut down, the spacecraft response in roll is reduced by a factor of four.

Since spacecraft response from the solar array drive overwhelms that of any instrument, all instrument jitter correlation studies must be made when the solar array drive is not operating.



JITTER CONTRIBUTION FROM S/A DRIVE



• RESPONSE REDUCED BY FACTOR OF 4 AFTER SHUTDOWN

JITTER CORRELATION STUDIES MUST BE
MADE WHEN SAD IS NOT OPERATING

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DATA PROCESSING FOR CALCULATING JITTER

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JITTER DETERMINATION

Instrument jitter is defined as the maximum peak to peak rotational excursion over a given time window. Instrument jitter must meet specifications or pointing inaccuracies will reduce instrument performance.

The four steps for converting gyro rate data to displacement data and then to jitter is discussed.



JITTER - MAXIMUM PEAK TO PEAK EXCURSION OVER A GIVEN TIME WINDOW

STEPS FOR COMPUTING JITTER FROM GYRO DATA

- 1) Telemetry data from gyros Δ counts/0.128 sec
1 count = 0.05 arcsec
- 2) Integrate to get position versus time
- 3) 50 sec forward/backward averaging to remove drift
- 4) Compute jitter using 2 a second sliding window

DATA PROCESSING (GYRO RATE DATA AND INTEGRATION)

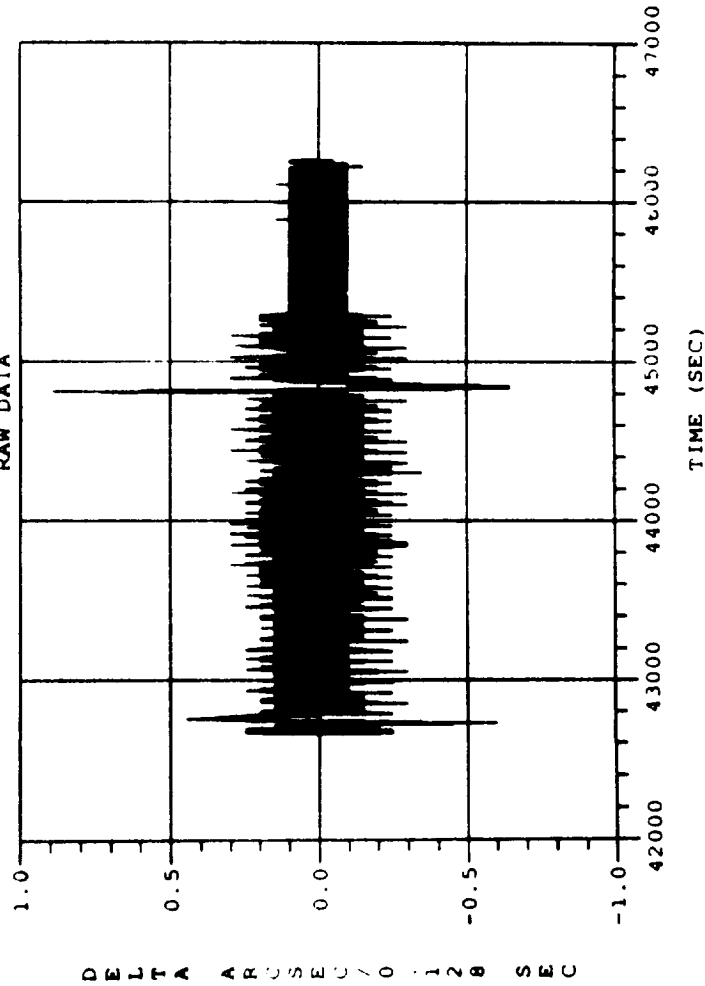
The gyros, located within MMS, measure the relative angular response of the spacecraft in roll, pitch, and yaw. Data is sampled every 0.128 seconds (7.81 Hz sampling rate) in counts where 1 count equals 0.05 arcseconds. The gyro generates rate data which must be integrated to get position. Gyros, however, are subject to drift rate error which creates a bias in the integrated data. In this example, the bias shows up as a positive slope in the integrated data.



DATA PROCESSING

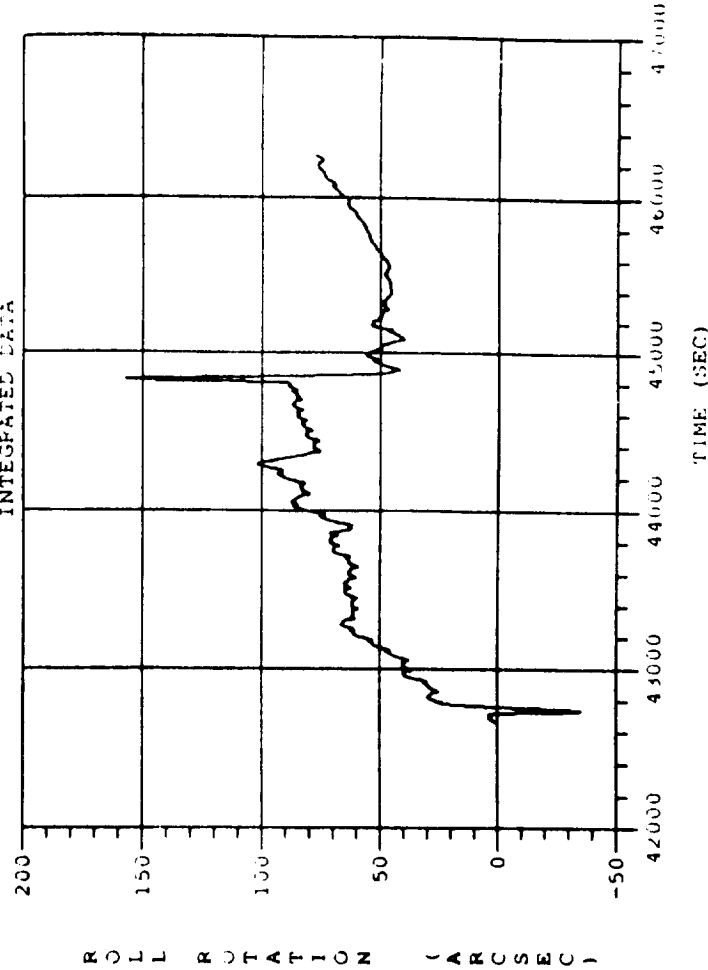
1) Gyro Rate Data

DAY 301 UARS ROLL GYRO ON ORBIT DATA
RAW DATA



2) Integrate Rate Data to Obtain Position

DAY 301 UARS ROLL GYRO ON ORBIT DATA
INTEGRATED DATA



GYRO DRIFT RATE ERROR CAUSES BIAS IN INTEGRATED DATA

DATA PROCESSING (DATA AVERAGING AND JITTER)

Drift rate error is not a constant but fluctuates with time. To remove the error, a forward/backward data averaging technique was employed. The average value over a 100 second window (50 seconds before and 50 seconds after) was subtracted from each data point. For disturbances which last less than 100 seconds, such as the MLS disturbance which repeats every 65 seconds, data averaging removes the bias without significantly distorting the time history response. For disturbances of more than 100 second duration, which include thermal snap and HGA/SSPP slew maneuvers, a larger time window is required otherwise the response will be distorted.

Using the unbiased data, jitter was determined using a sliding 2 second window. The distance between the maximum and minimum response over the previous 2 seconds, i.e. jitter, is determined and plotted as a function of time. The jitter time history was used for analyzing different portions of the disturbance and their effect on jitter.

The 2 second jitter window was based on the WINDII requirement of 4 arcseconds jitter per 2 seconds. This was the tightest requirement of any UARS instrument.

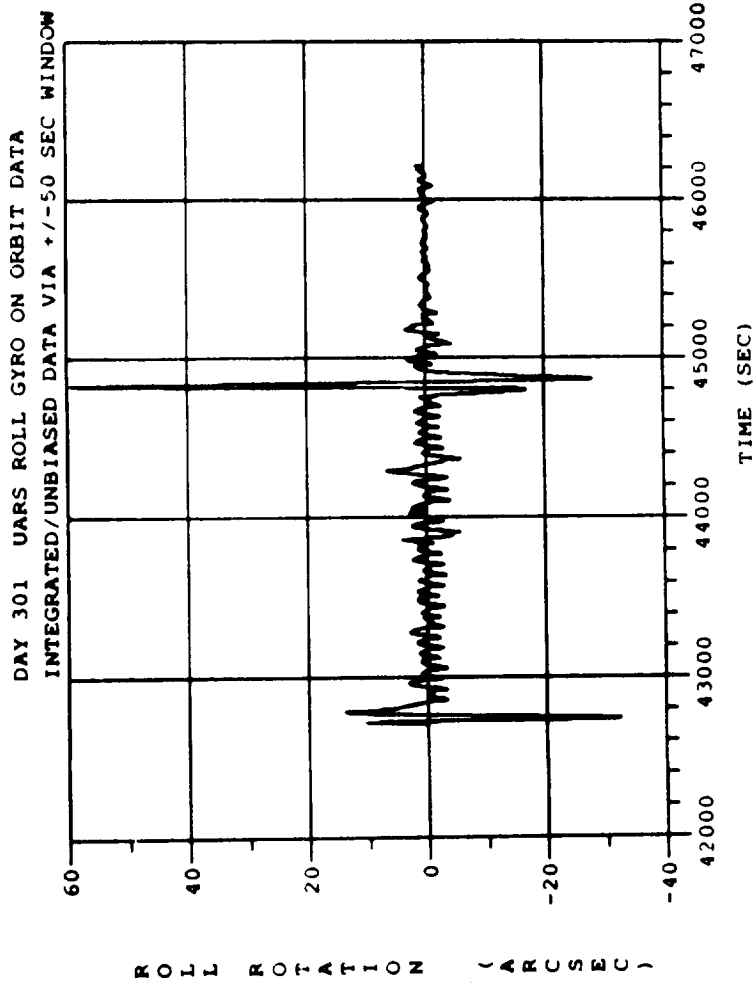


UARS JITTER STUDY

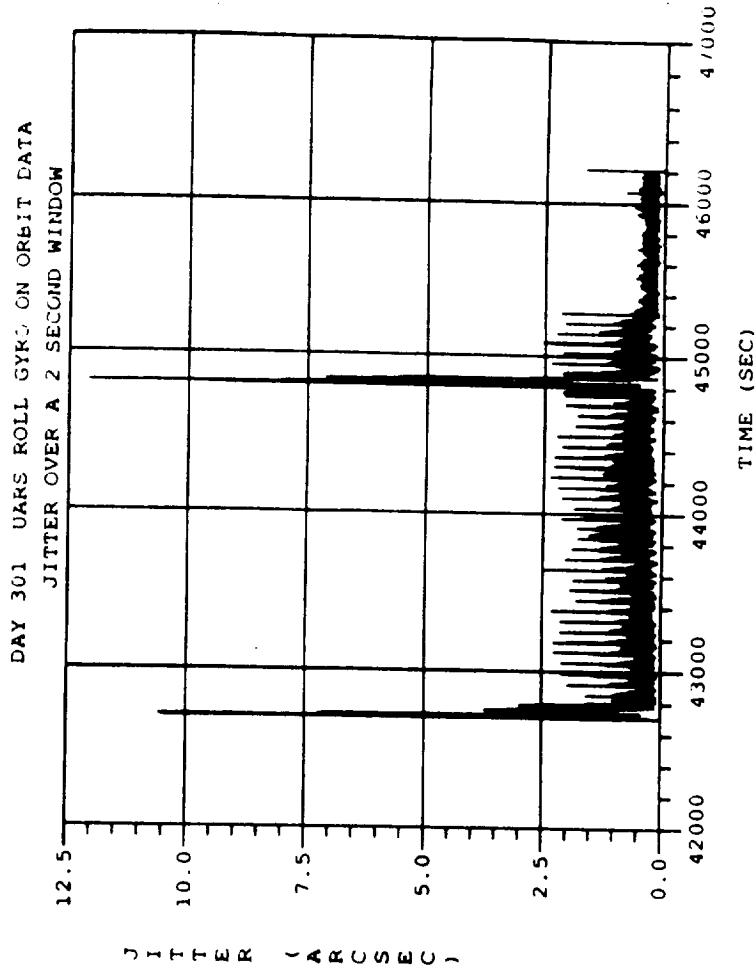
DATA PROCESSING

81

3) Bias Removed Via ± 50 sec window averaging



4) Jitter Calculated over 2 sec window



DATA AVERAGING USED TO REMOVE BIAS FROM INTEGRATED DATA

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UARS JITTER STUDY

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FLIGHT REACTION WHEEL JITTER

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FLIGHT REACTION WHEEL JITTER

Day 266 (June 3, 1992) gyro data was analyzed to compare spacecraft jitter for reaction wheels operating at their nominal high rate versus operating at a slower safe hold rate. UARS has four reaction wheels which are controlled by the attitude control system to counteract disturbances on board the spacecraft. Three of the reaction wheels act about the spacecraft roll, pitch, and yaw axes (X, Y, and Z). The fourth reaction wheel acts about a skew axis.

For the time period of interest, the solar array drive is off, positioned at 278 degrees, and the HGA is tracking.



- ORIGINALLY CONCERNED THAT RWAS MAY BE CAUSING "BEATING" EFFECT SEEN IN GYRO DATA
- ANALYZED DAY 266 GYRO DATA WHEN SPACECRAFT WENT INTO SAFE HOLD MODE
- COMPARE SPACECRAFT JITTER WHEN RWAS ROTATING AT THE NOMINAL HIGH RATE AND SAFE HOLD SLOW RATE
- DATA PROVIDES LEVEL OF QUIESCENT JITTER

X AND Y REACTION WHEELS

The X and Y reaction wheel momentum data is plotted versus time for Day 266. The x-axis on each plot represents the number of seconds into the day. The y-axis is angular momentum in Newton-meter-seconds. For time period 1, the reaction wheels are operating at their normal high rate. For time period 2, the reaction wheels have slowed down to the safe hold rate.



UARS JITTER STUDY

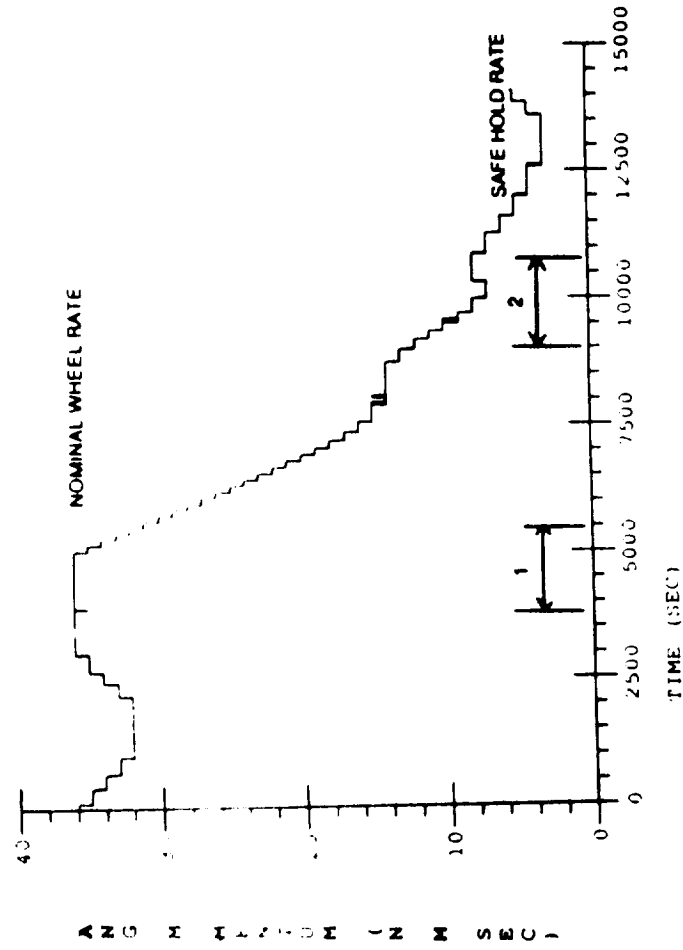
REACTION WHEELS

87

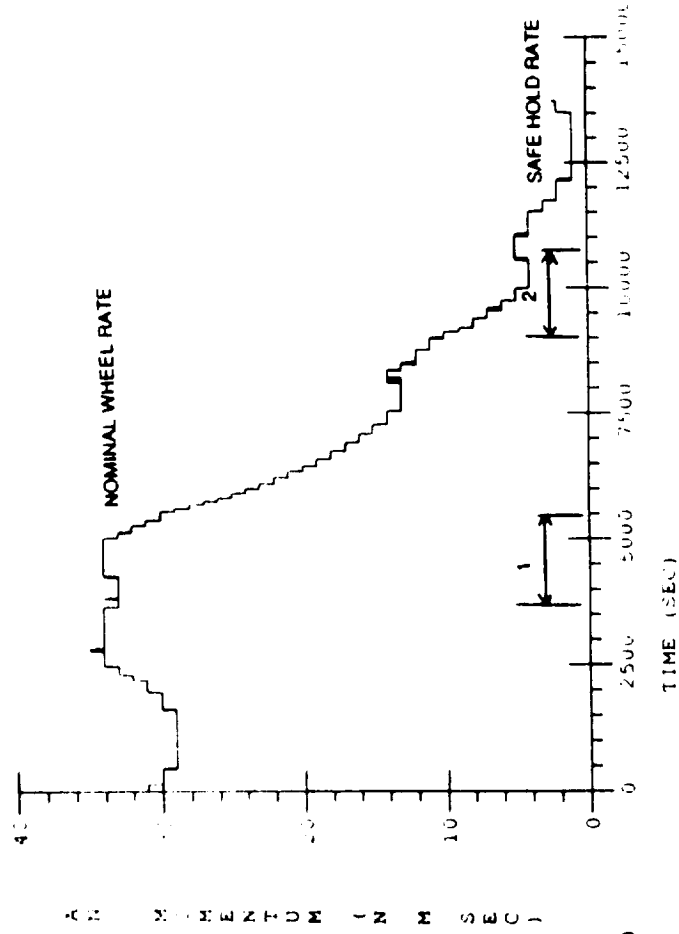
- HGA TRACKING
- ALL OTHER INSTRUMENTS OFF

DAY 266 X WHEEL DAY 266 Y WHEEL

DAY 266 X MOMENTUM WHEEL



DAY 266 Y MOMENTUM WHEEL



X AND Y WHEELS SLOW DOWN DURING SAFE HOLD MODE

Z AND SKEW REACTION WHEELS

Momentum data for the Z and Skew wheels are plotted for the same time window as the X and Y wheels shown previously. Both wheels are operating at their nominal rate in time period 1. In time period 2, the Z wheel has slowed down while the Skew wheel has stopped entirely by time approximately 10,000 seconds.



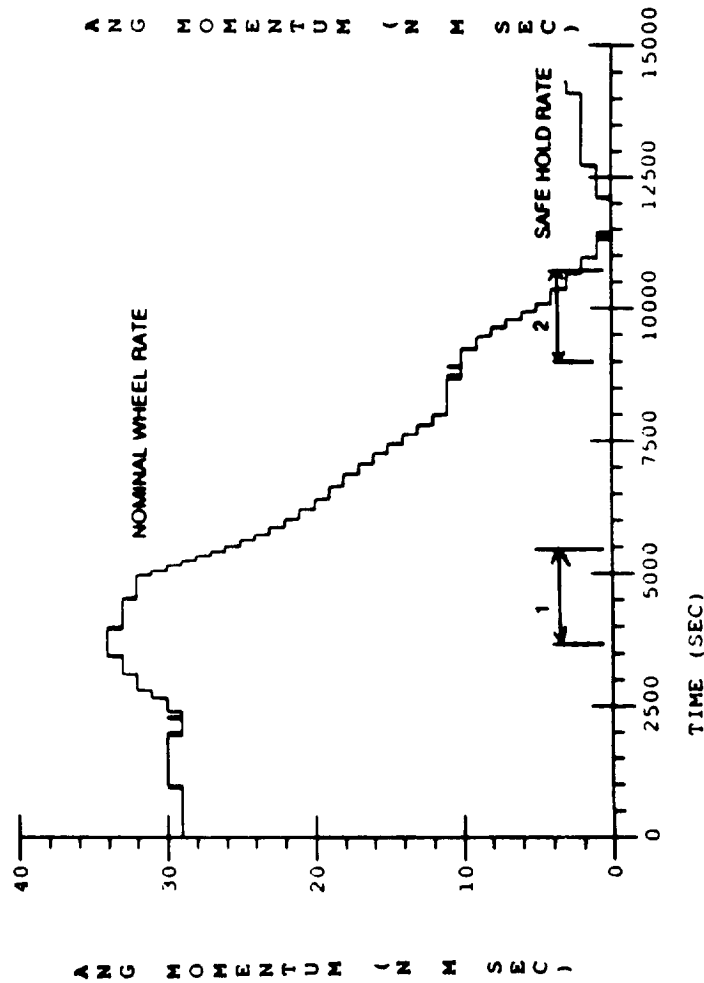
REACTION WHEELS

89

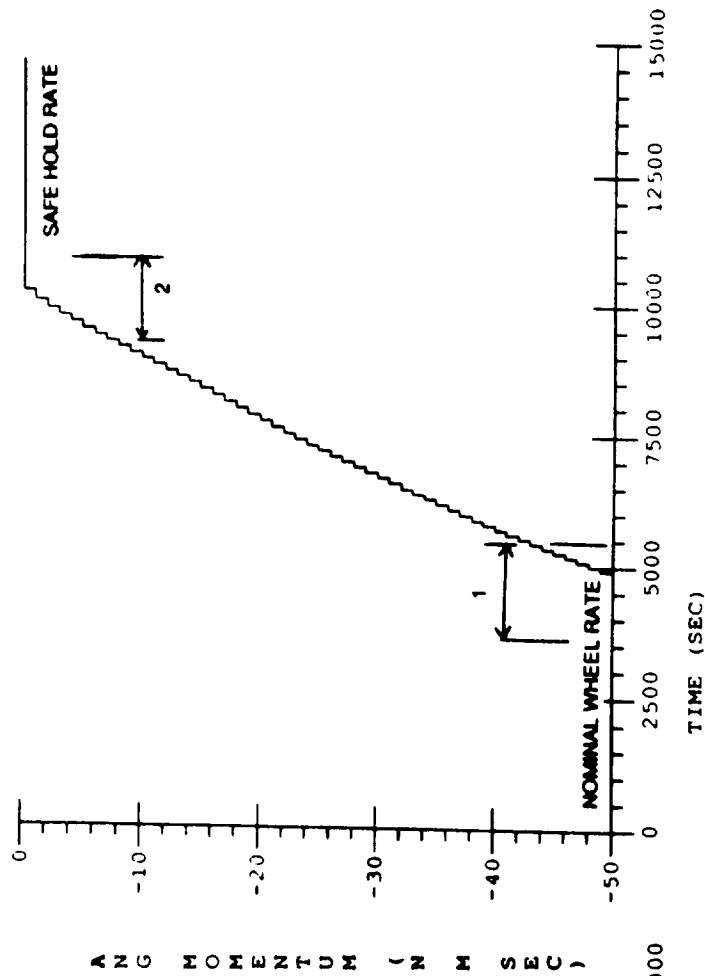
- HGA TRACKING
- ALL OTHER INSTRUMENTS OFF

DAY 266 Z WHEELDAY 266 SKEW WHEEL

DAY 266 Z MOMENTUM WHEEL



DAY 266 SKEW MOMENTUM WHEEL



Z WHEEL SLOWS DOWN DURING SAFE HOLD MODE
SKEW WHEEL STOPS

RWA ROLL JITTER

Roll jitter is plotted as a function of time for both time period 1(normal operation) and time period 2 (safe hold). The jitter level does not change after the reaction wheels slow down to the safe hold rate. During normal operation, jitter peaks at roughly 0.70 arcseconds until the reaction wheels begin to reduce speed at 4900 seconds. After 10,000 seconds, when the reaction wheels have reached their safe hold rate, jitter peaks at 0.65 arcseconds.

Jitter due to the momentum wheel change, thermal snap, and HGA/SSPP slew maneuvers have been distorted by data averaging since the disturbances all take longer than 100 seconds. These disturbances, discussed in section DAY 266 HGA AND SSPP JITTER, require a data averaging window of more than 100 seconds.



UARS JITTER STUDY

RWA JITTER

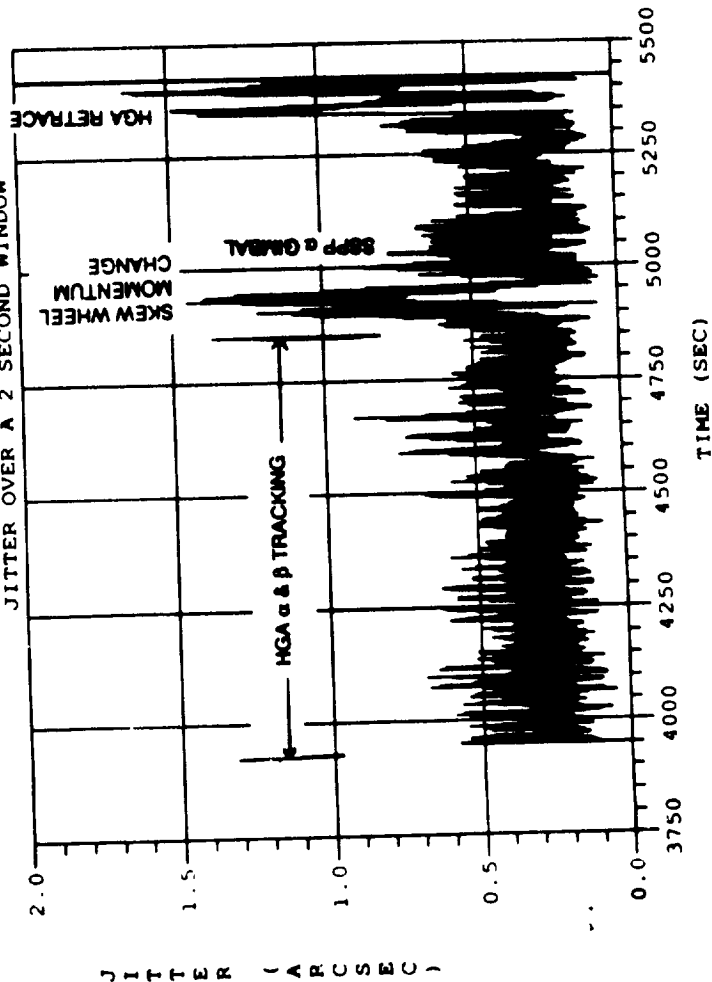
91

ROLL JITTER (± 50 SECOND WINDOW AVERAGING)

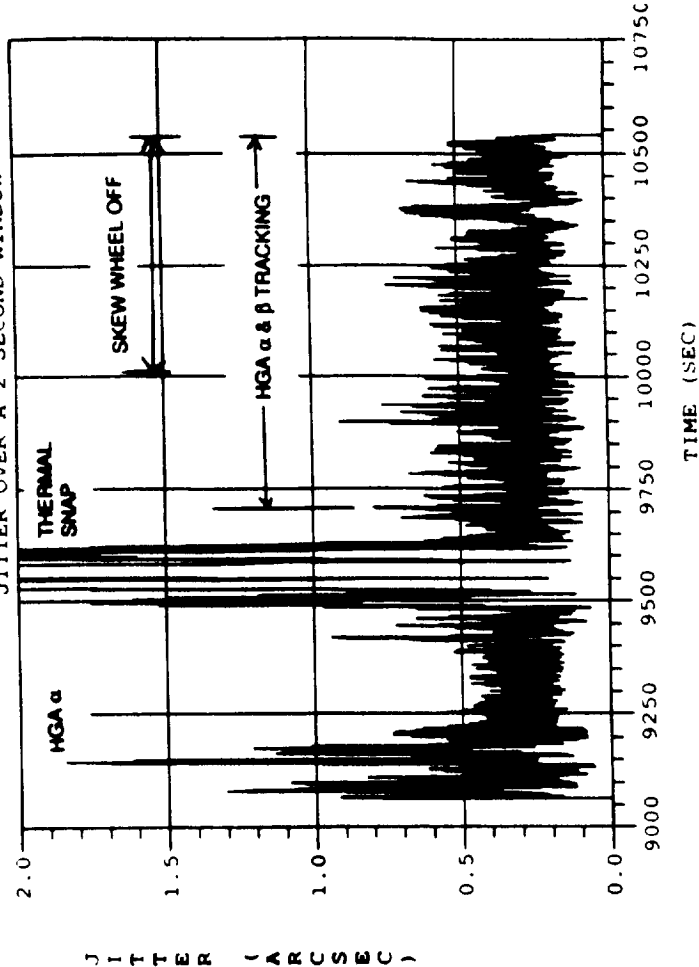
NORMAL OPERATION

SAFE HOLD

DAY 266 UARS ROLL GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



DAY 266 UARS ROLL GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



NO CHANGE IN ROLL JITTER AFTER RWA SLOWDOWN

RWA PITCH JITTER

The level of pitch jitter is the same, approximately 0.45 arcseconds, at both the normal and safe hold reaction wheel rates.



UARS JITTER STUDY

RWA JITTER

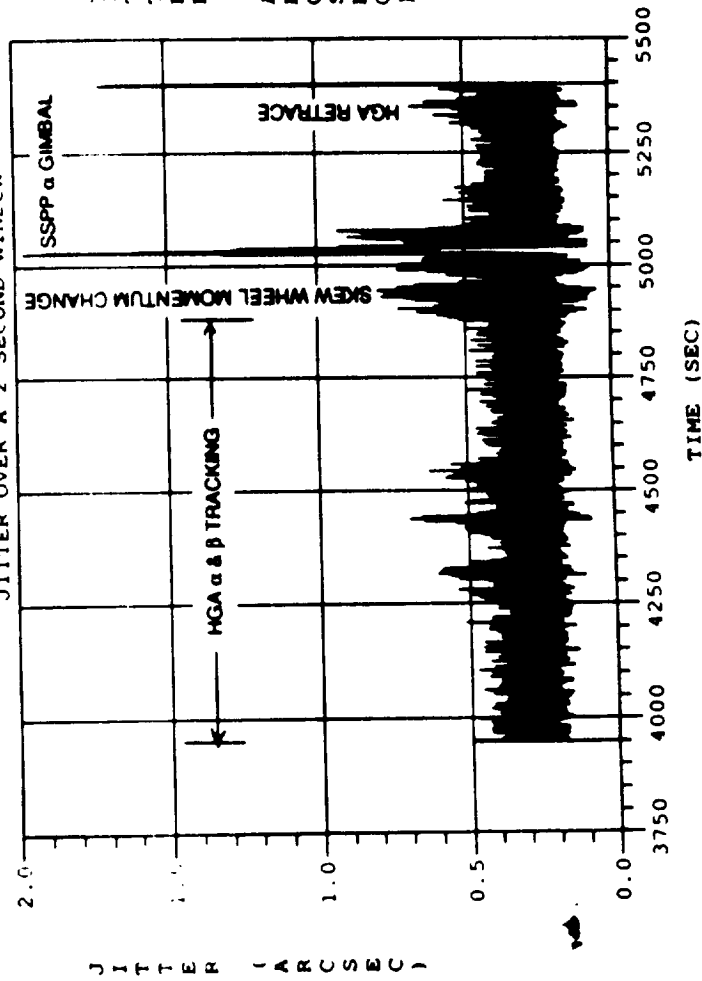
93

PITCH JITTER (± 50 SECOND WINDOW AVERAGING)

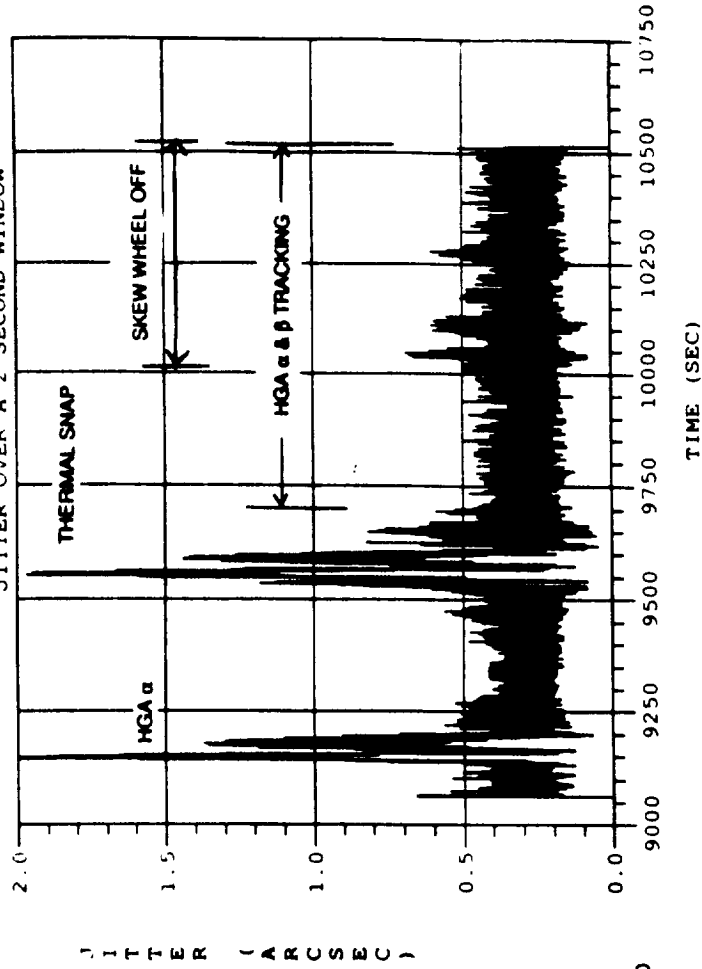
NORMAL OPERATION

SAFE HOLD

DAY 266 UARS PITCH GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



DAY 266 UARS PITCH GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



NO CHANGE IN PITCH JITTER AFTER RWA SLOWDOWN

RWA YAW JITTER

The level of yaw jitter is the same, approximately 0.55 arcseconds, at both the normal and safe hold reaction wheel rates.



UARS JITTER STUDY

RWA JITTER

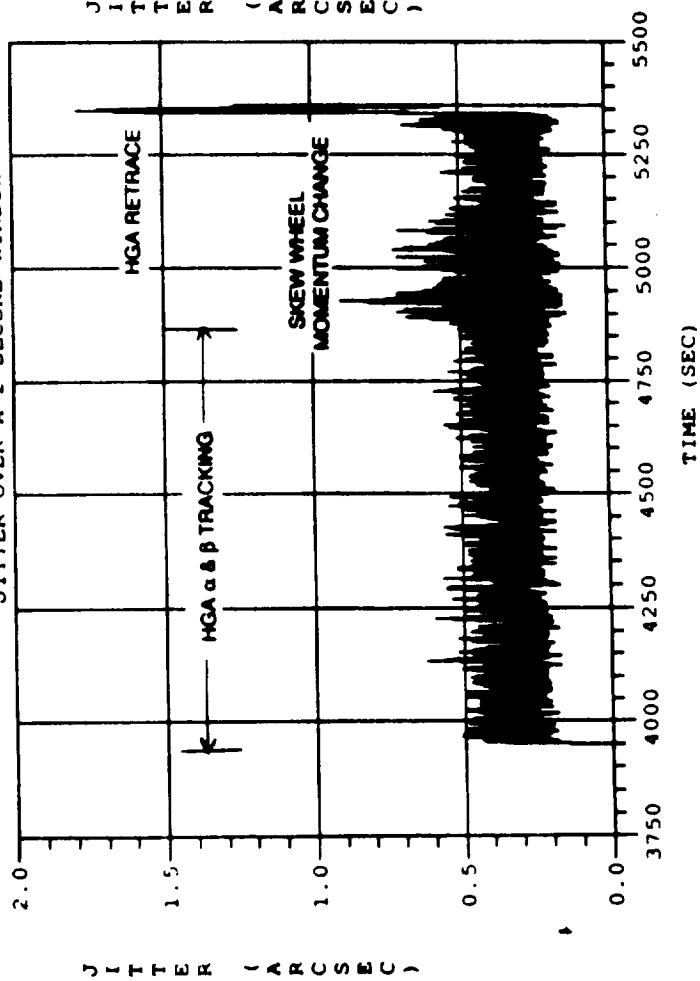
95

YAW JITTER (± 50 SECOND WINDOW AVERAGING)

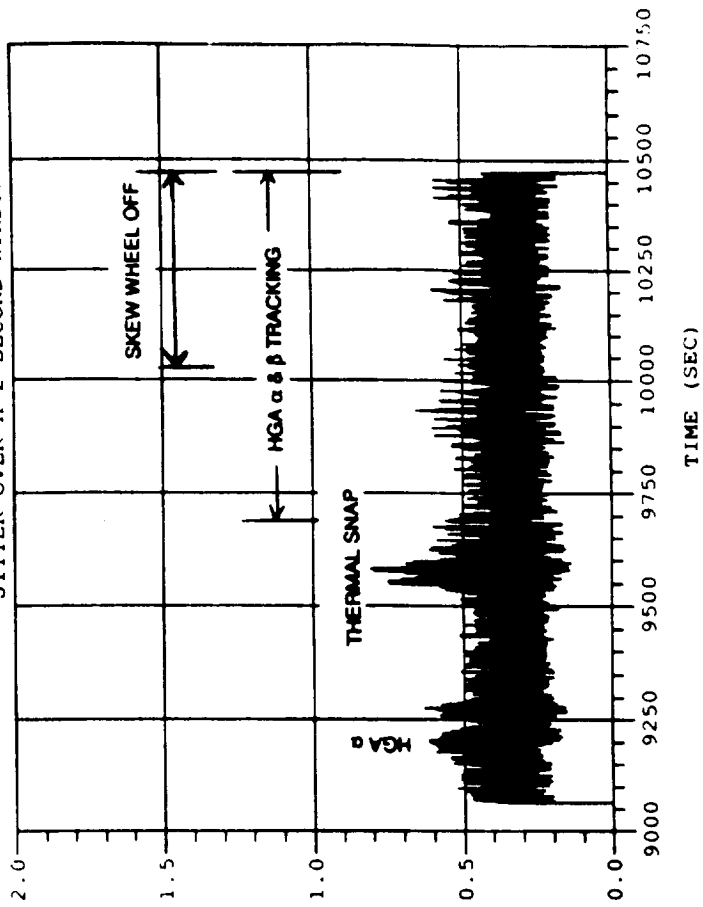
NORMAL OPERATION

SAFE HOLD

DAY 266 UARS YAW GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



DAY 266 UARS YAW GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



NO CHANGE IN YAW JITTER AFTER RWA SLOWDOWN

QUIESCENT JITTER

The level of roll jitter due to the HGA tracking, momentum wheels, and attitude control system was calculated for different time windows. The time windows are identical to those used for EOS except for 0.1 seconds, which could not be used since data was sampled only every 0.128 seconds.

The safe hold mode was expected to be quieter since the reaction wheels generate lower forces due to lower rotation rates. Since jitter for the normal and safe hold reaction wheel rates vary little, it was concluded that normal operation of reaction wheels has no significant effect on flight jitter values. The only detectable effect on jitter occurred during the sudden change in momentum when the wheels first started into their safe hold mode.



QUIESCENT JITTER

JITTER DUE TO: HGA TRACKING
MOMENTUM WHEELS
ATTITUDE CONTROL SYSTEM

ROLL JITTER FOR EOS TIME WINDOWS

EOS TIME WINDOW	UARS FLIGHT TIME WINDOW	TIME PERIOD 1		TIME PERIOD 2	
		NORM OPER	JITTER	SAFE HOLD	JITTER
0.1	0.128	0.10	0.10	0.45	0.10
1	1	0.40	0.40	0.65	0.45
1.8	1.8	0.70	0.70	0.65	0.65
	2	0.70	0.70	1.25	0.65
9	9	1.20	1.20	4.20	1.25
55	55	3.80	3.80	4.20	4.20
420	420	3.80	3.80	4.20	4.20

NORMAL OPERATION OF REACTION WHEELS HAS
NO EFFECT ON FLIGHT JITTER VALUES

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UARS JITTER STUDY

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MLS JITTER CORRELATION

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MLS SENSOR

The Microwave Limb Sounder (MLS) instrument measures the thermal emission of selected spectral lines in the earth's limb at millimeter wavelengths. It has a signal collecting antenna which scans in motor driven steps about the UARS roll axis. The antenna scans a total distance of 1.84 degrees in 65.5 seconds (1 encoder position equals .0025 degrees). The scan is normally continually repeated. The effective instrument moment of inertia for the antenna scan is $24880 \text{ lb}_m \text{ in}^2$.

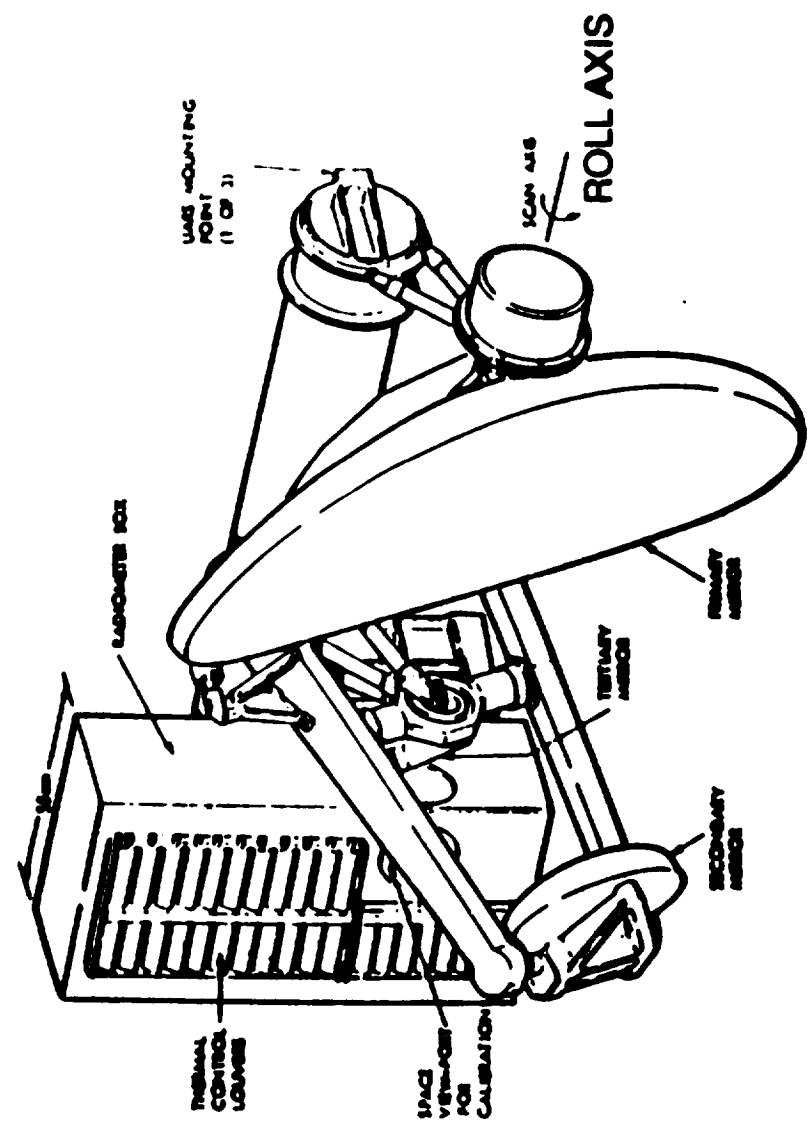
The other potential mechanical disturbance element in MLS is an internal switching mirror which selects the radiation source (limb, space, or internal target). It switches between these three positions (1, 2, and 3 on the chart) in a continuous fashion. The level of disturbance due to the switching mirror is small as compared to that of the antenna and was ignored for the analytical jitter analysis.



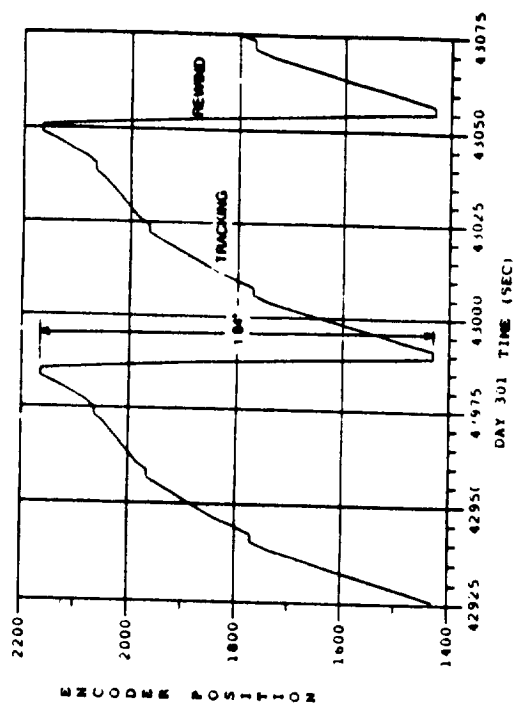
UARS JITTER STUDY MLS SENSOR

101

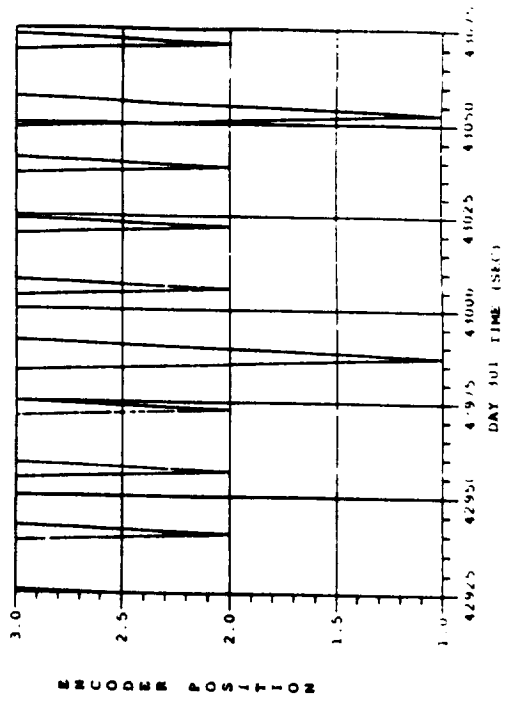
MLS SENSOR



ANTENNA SCAN



SWITCHING MIRROR SCAN



BOTH SCANS REPRESENT TYPICAL FLIGHT DATA

MLS ANTENNA SCAN TORQUE PROFILE

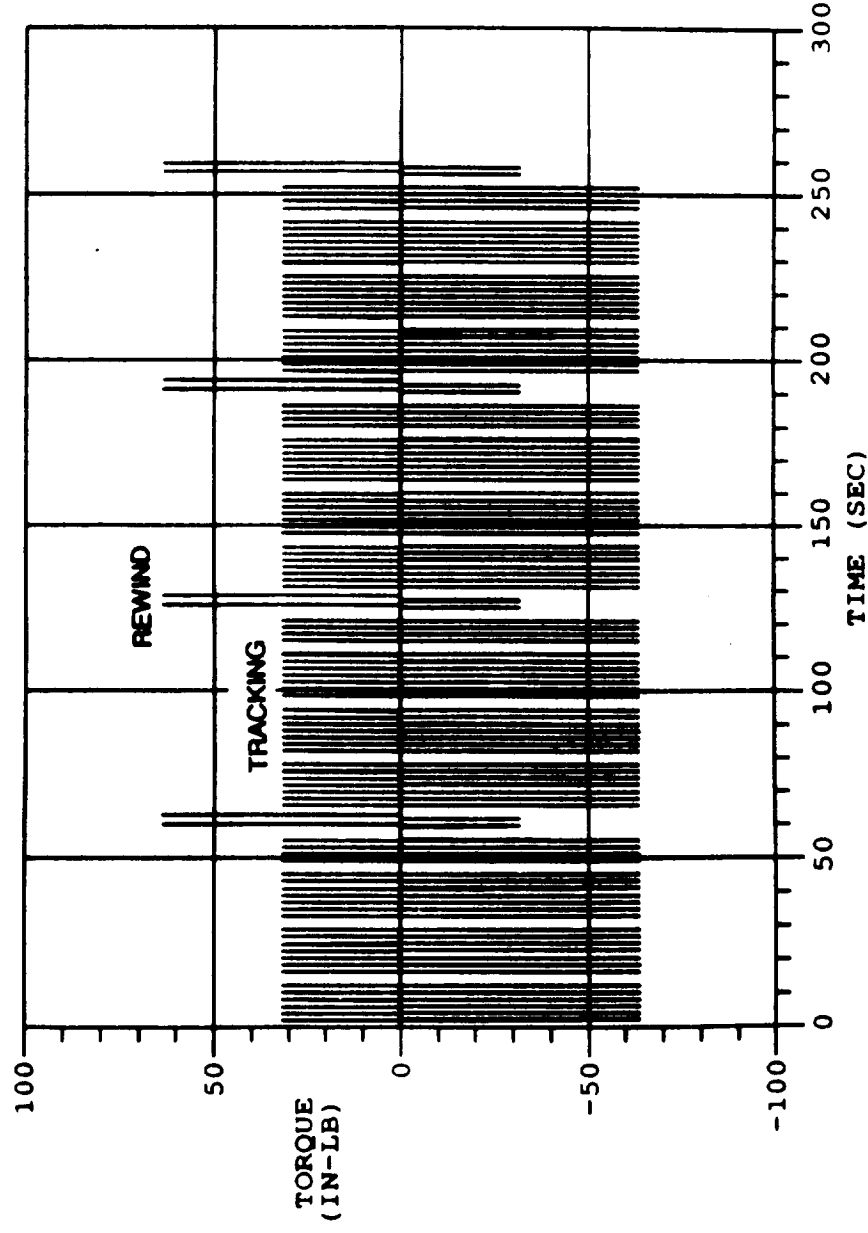
The analytical torque profile used to simulate the MLS antenna disturbance is shown for four repeat scans. Each scan consists of 25 forward pulses (tracking) and 2 return pulses (retrace). The pulses occur every 2.048 seconds.

The distance traveled during each pulse depends on the time increment between the start and stop impulse. The start/stop time increment was adjusted for each forward and reverse pulse to match the telemetry data position.

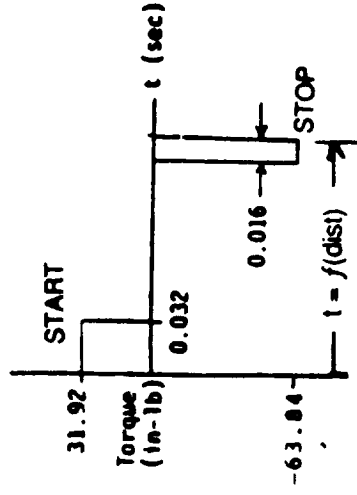


MLS ANTENNA SCAN TORQUE PROFILE

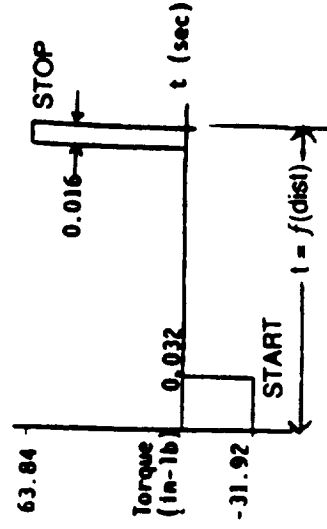
4 REPEAT SCANS



TRACKING PULSE



REWIND PULSE



UPDATED TORQUE PROFILE TO SIMULATE FLIGHT OPERATIONS

ANALYTICAL RESPONSE TO THE MLS DISTURBANCE (0.2% ANALYTICAL DAMPING)

The analytical response to the MLS disturbance was calculated assuming no Attitude Control System (ACS) with the solar array stationary and positioned at 270 degrees. The conservative pre-launch estimate of 0.2% critical damping for all modes was also assumed. The spacecraft response and jitter over a 2 second window were calculated at the gyro location for 10 complete scans.



UARS JITTER STUDY

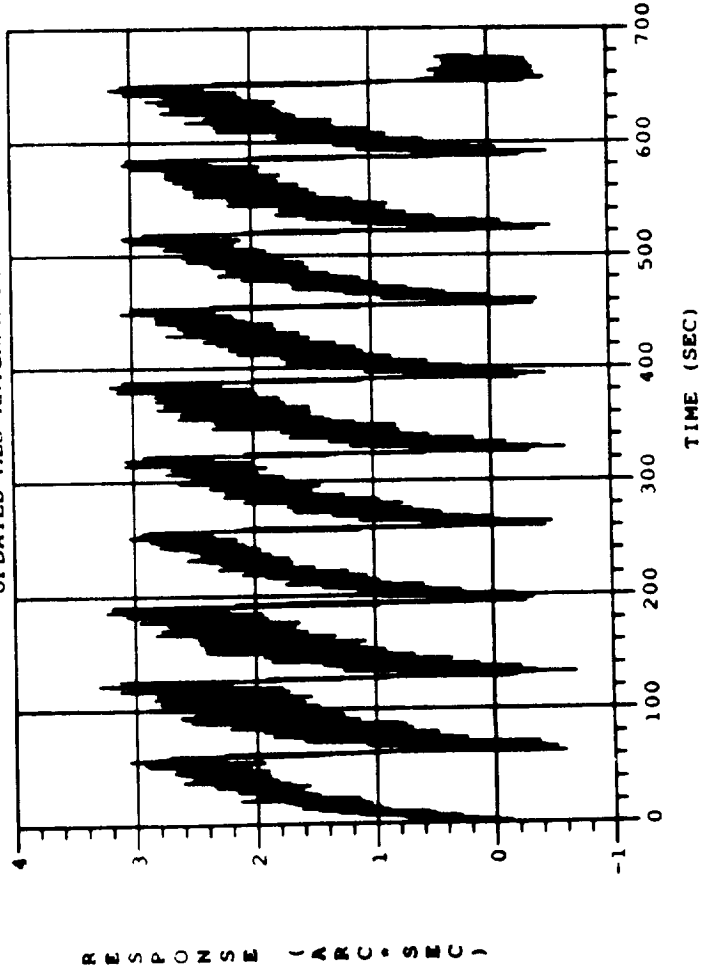
ANALYTICAL RESPONSE TO MLS DISTURBANCE 105

- No Controller
- S/A 270°
- 0.2% C/Cc Damping

ROLL AXIS

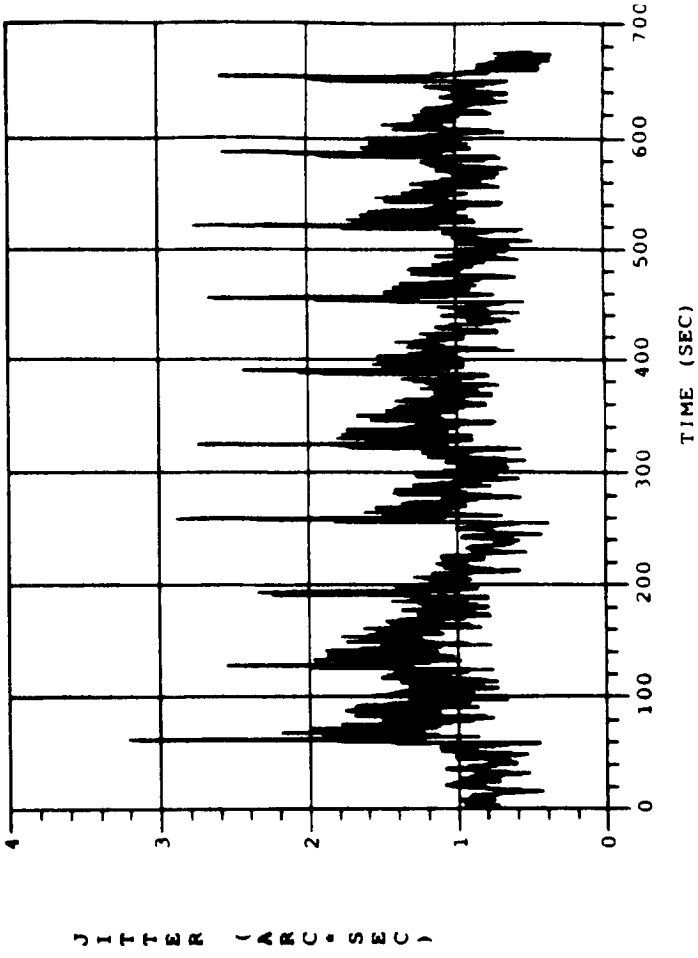
Time History

NMS 4876 THETA X RESPONSE
UPDATED MLS ANTENNA DISTURBANCE



Jitter

NMS 4876 THETA X JITTER OVER 2 SEC WINDOW
UPDATED MLS ANTENNA DISTURBANCE



RESPONSE FROM 10 MLS SCANS

ANALYTICAL RESPONSE FOR 2 FULL MLS SCANS (0.2% ANALYTICAL DAMPING)

Response and jitter are shown for a smaller time window covering two complete MLS scans.

During the tracking portion of the scan, flexible motion, primarily involving the solar array flatwise mode, dominates the response. Jitter during tracking (between the 2.5 arcsecond spikes) fluctuates around 1.4 arcseconds. Of the total jitter during tracking, rigid body motion accounts for an average of 0.10 arcseconds.

3 arcsecond rotation / 60 seconds of tracking * 2 second jitter window = 0.10 arcsecond

Maximum rigid body jitter is 0.20 arcseconds and occurs at the beginning of the scan (when the antenna has its highest tracking rate).

The retrace portion of the scan is performed with two return pulses that produce primarily rigid body motion. The two pulses generate 1.9 and 2.6 arcseconds of jitter. Of this total jitter, rigid body motion accounts for 1.15 and 1.84 arcseconds, respectively.



UARS JITTER STUDY

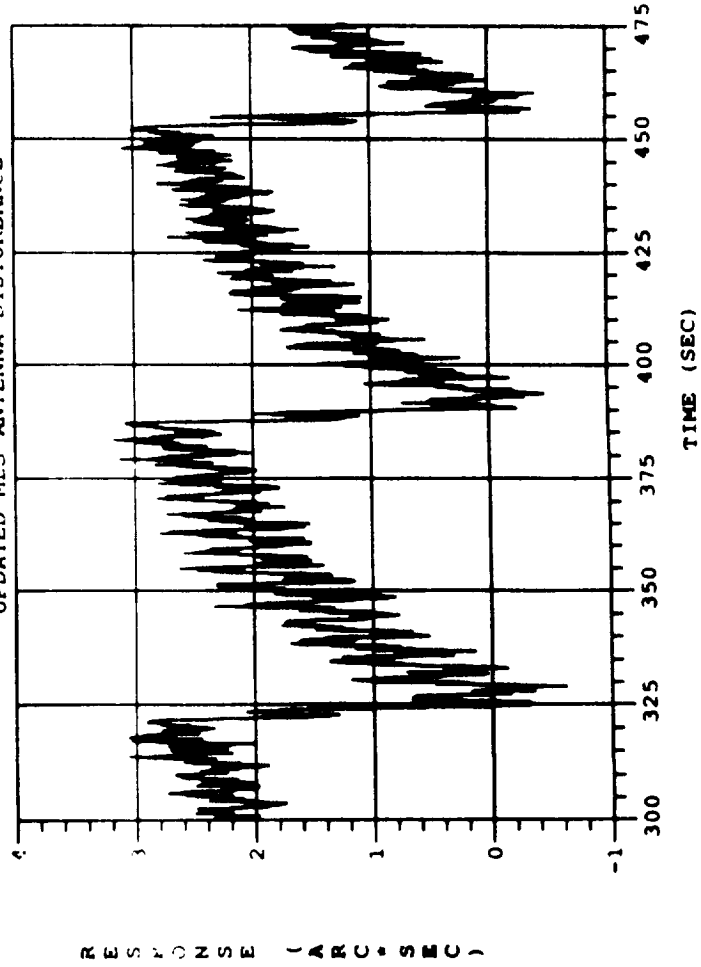
ANALYTICAL RESPONSE FOR 2 FULL MLS SCANS 107

- No Controller
- S/A 270°
- 0.2% C/Cc Damping

ROLL AXIS

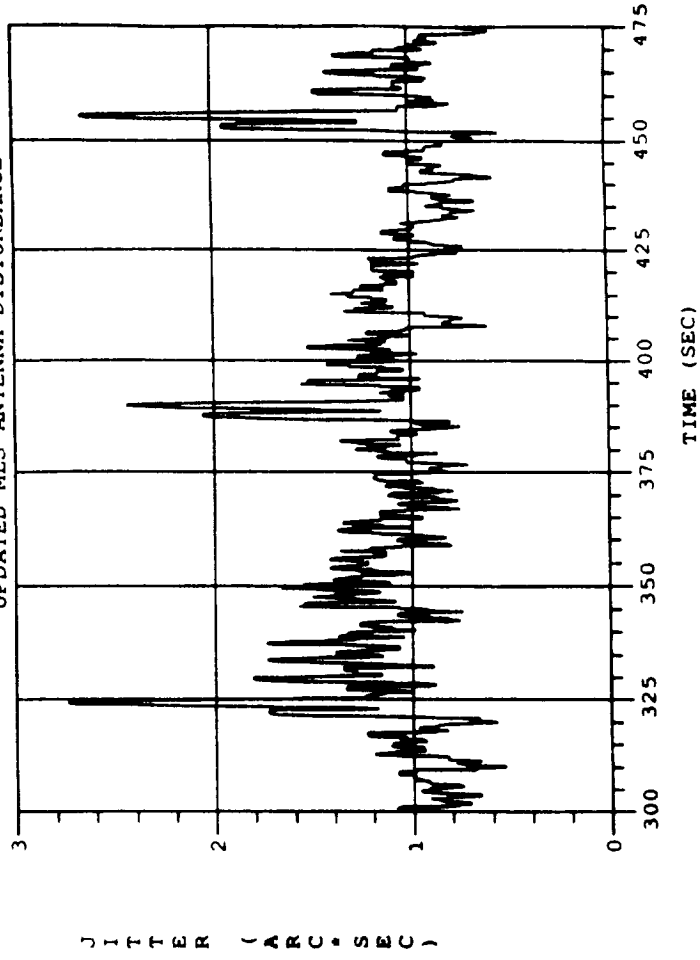
Time History

MMS 4876 ROLL RESPONSE S/A 270 DEG
UPDATED MLS ANTENNA DISTURBANCE



Jitter

MMS 4876 ROLL JITTER OVER 2 SEC WINDOW
UPDATED MLS ANTENNA DISTURBANCE



APPROXIMATELY 1.4 ARCSEC JITTER BETWEEN RETURN SCANS

FLIGHT DATA DURING MLS SHUTDOWN (ROLL AXIS)

Flight gyro data and jitter is shown for a one hour time period covering the Day 301 MLS shutdown. Besides MLS, other disturbance sources include HGA tracking, reaction wheels, and the ACS.

The spacecraft response is noticeably reduced after the MLS shutdown. The 2 arcsecond spikes in the jitter data disappear. In addition, the level of jitter between spikes is also reduced. The spikes, which occur every 65 seconds, are produced by the MLS antenna retrace.



UARS JITTER STUDY

FLIGHT DATA DURING MLS SHUTDOWN

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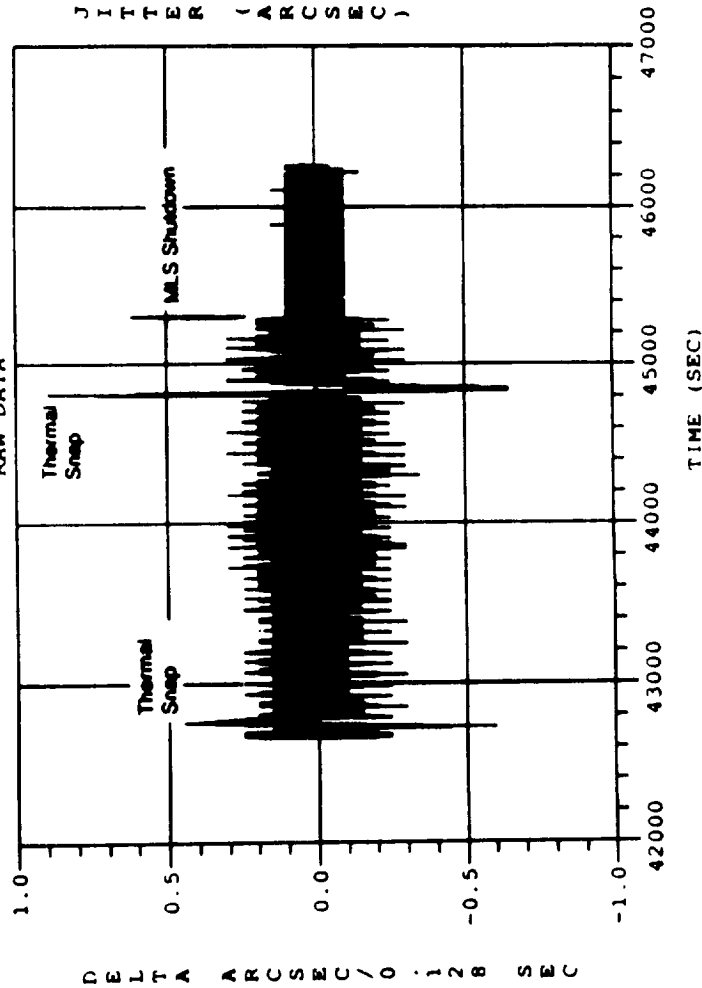
- S/A drive shutdown with S/A positioned at 278°
- MLS scanning until shutdown
- HGA tracking
- All other instruments off

GYRO DATA

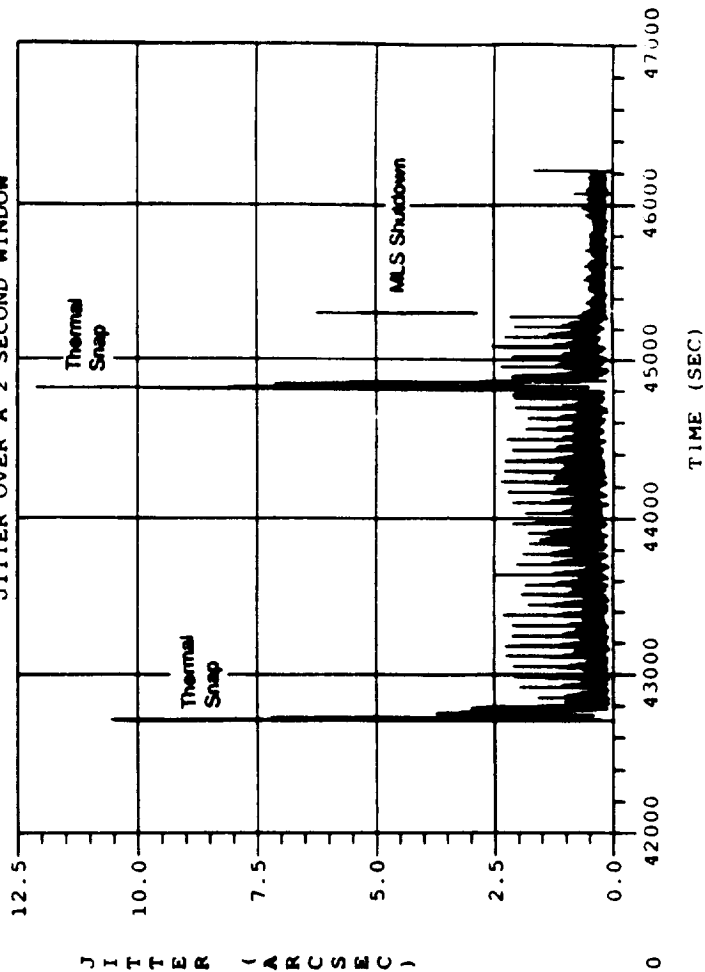
ROLL AXIS

JITTER

DAY 301 UARS ROLL GYRO ON ORBIT DATA
RAW DATA



DAY 301 UARS ROLL GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



SIGNIFICANT REDUCTION IN ROLL JITTER AFTER MLS SHUTDOWN

FLIGHT DATA DURING MLS SHUTDOWN (PITCH AXIS)

The pitch gyro and jitter data is shown for the same one hour time period previously shown for roll. Unlike roll, the pitch response does not noticeably change after the MLS shutdown. Consequently, MLS does not contribute to flight jitter in pitch.

Analytically, pitch jitter reaches 0.35 arcseconds during retrace and 0.20 arcseconds during tracking (assuming 0.2 % modal damping).



UARS JITTER STUDY

FLIGHT DATA DURING MLS SHUTDOWN

111

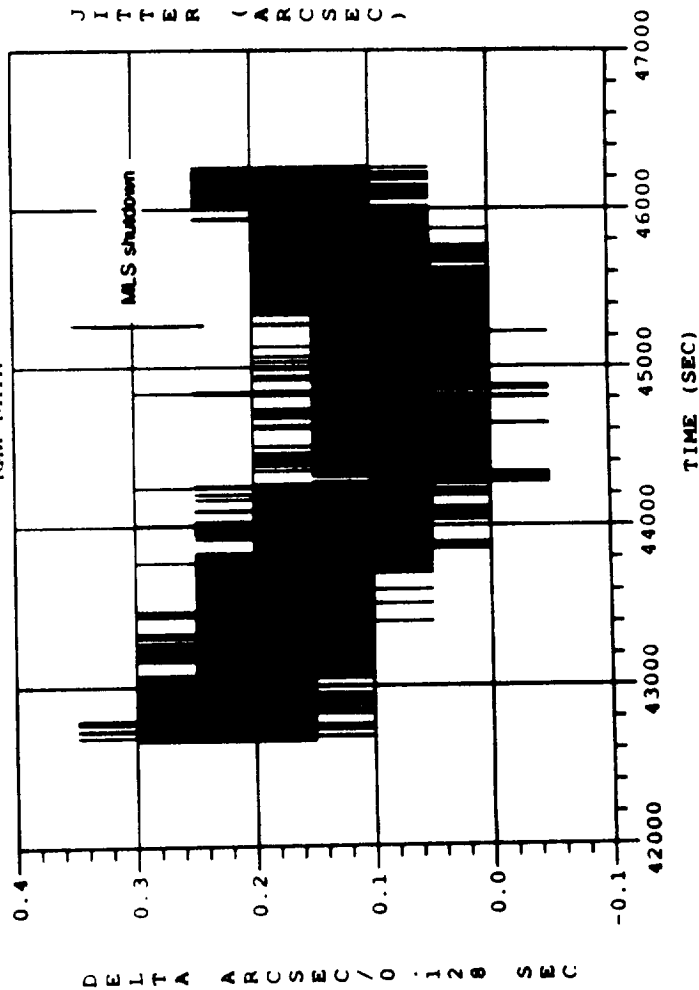
- S/A drive shutdown with S/A positioned at 278°
- MLS scanning until shutdown
- HGA tracking
- All other instruments off

GYRO DATA

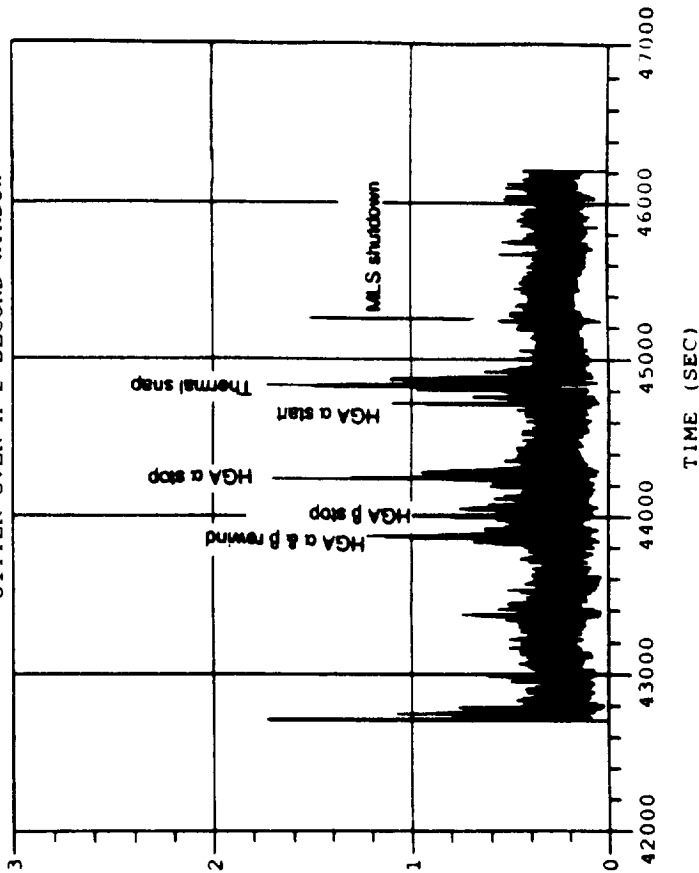
PITCH AXIS

JITTER

DAY 301 UARS PITCH GYRO ON ORBIT DATA
RAW DATA



DAY 301 UARS PITCH GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



MLS DOES NOT CONTRIBUTE TO PITCH JITTER

FLIGHT DATA DURING MLS SHUTDOWN (YAW AXIS)

The yaw gyro and jitter data also does not noticeably change after the MLS shutdown. As in the pitch axis, MLS does not contribute to flight jitter in yaw.

Analytically, yaw jitter reaches 0.175 arcseconds during retrace and 0.15 arcseconds during tracking (assuming 0.2 % modal damping).



UARS JITTER STUDY

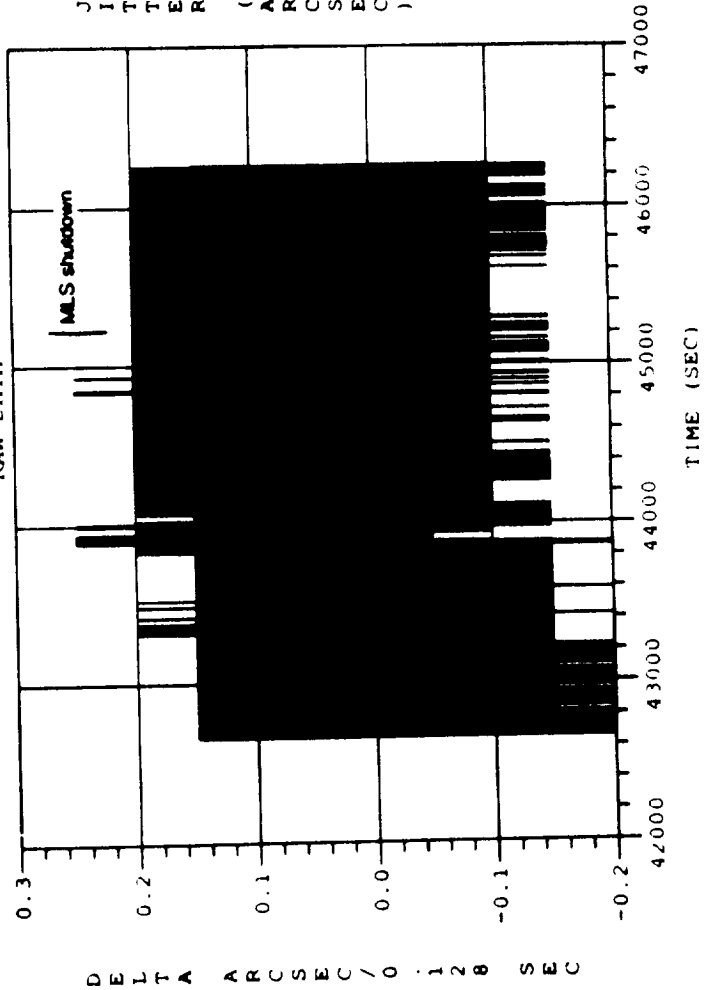
FLIGHT DATA DURING MLS SHUTDOWN

113

- S/A drive shutdown with S/A positioned at 278°
- MLS scanning until shutdown
- HGA tracking
- All other instruments off

GYRO DATA

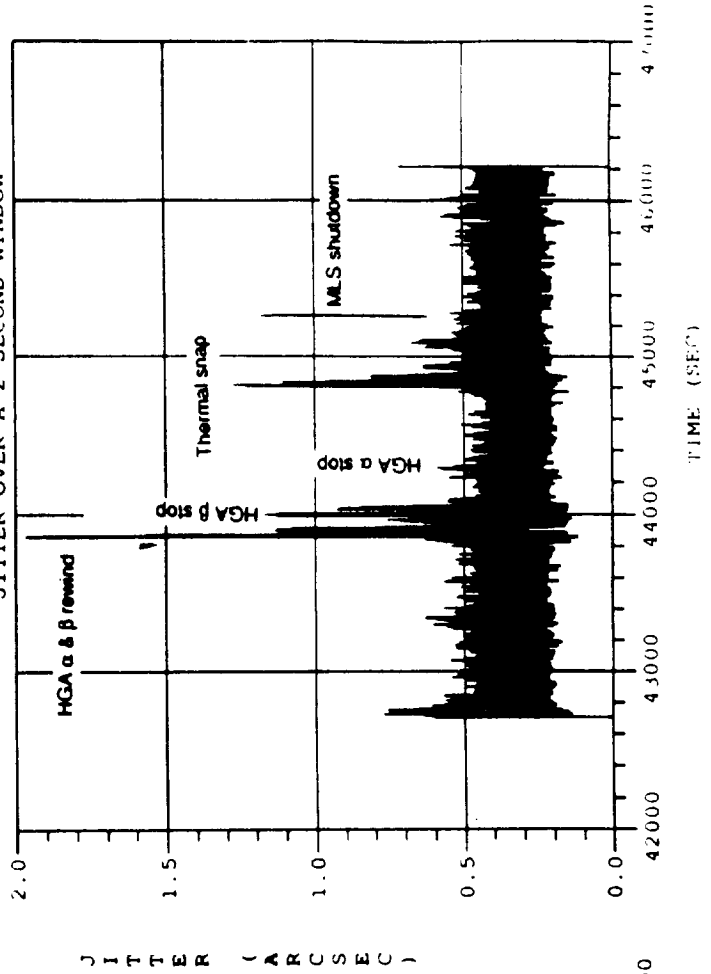
DAY 301 UARS YAW GYRO ON ORBIT DATA
RAW DATA



YAW AXIS

JITTER

DAY 301 UARS YAW GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



MLS DOES NOT CONTRIBUTE TO YAW JITTER

FLIGHT RESPONSE TO MLS DISTURBANCE (ROLL AXIS)

Flight time history response and jitter is shown for a period covering 10 MLS scans on Day 301. Besides MLS, the only other disturbance sources include HGA tracking, reaction wheels, and the ACS.



UARS JITTER STUDY

FLIGHT RESPONSE TO MLS DISTURBANCE 115

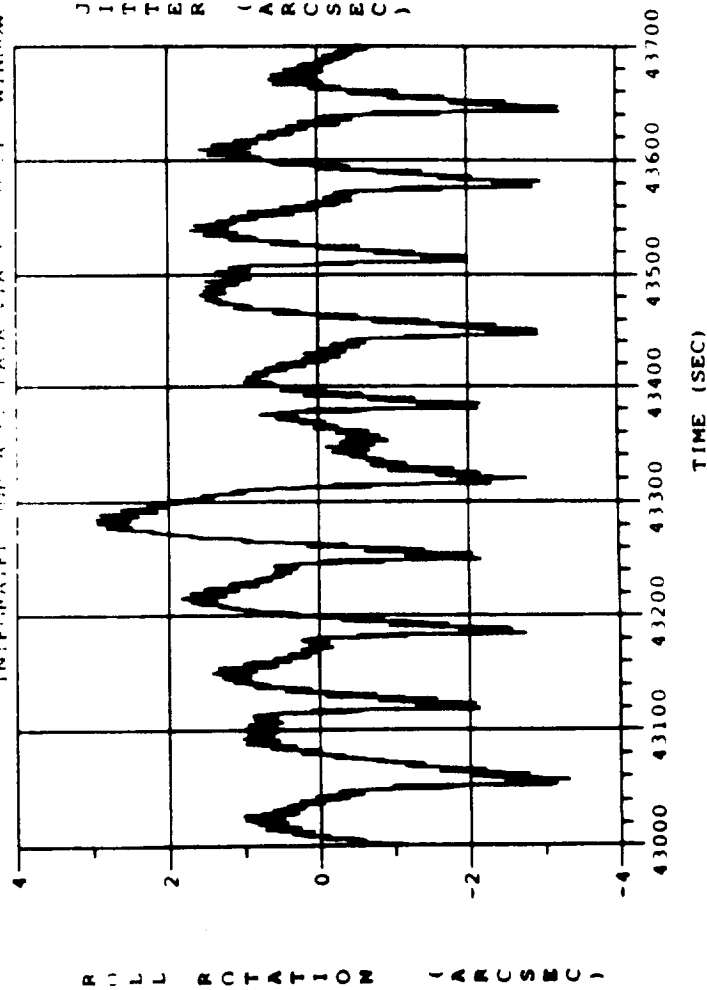
- S/A drive shutdown with S/A positioned at 278°
- MLS scanning
- HGA tracking
- All other instruments off

Time History

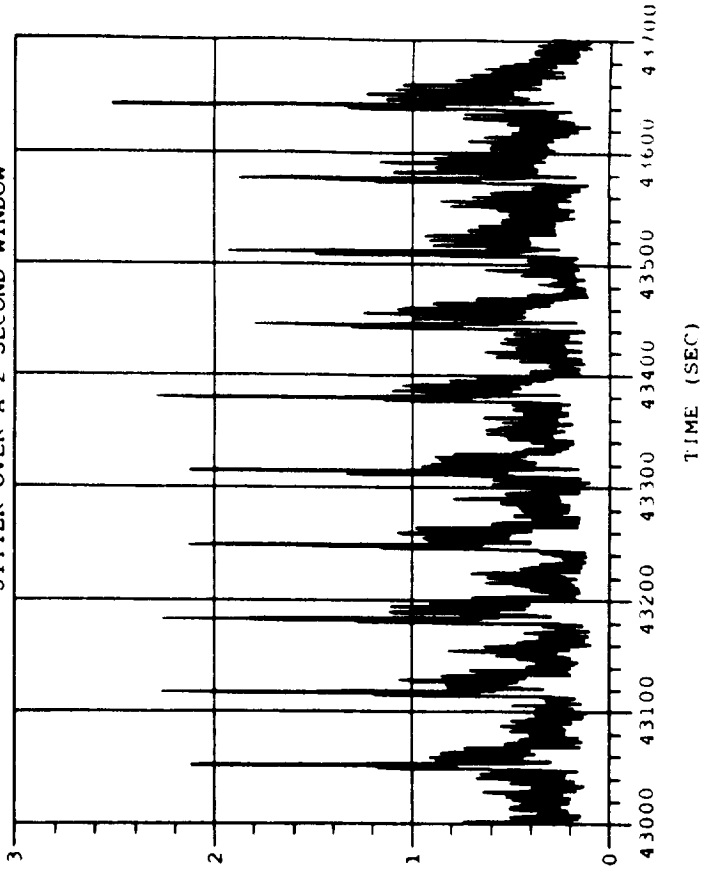
ROLL AXIS

Jitter

DAY 301 UARS ROLL GYRO ON ORBIT DATA
INTEGRATED OVER A 2 SECOND WINDOW



DAY 301 UARS ROLL GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



APPROXIMATELY 0.4 ARCSEC JITTER BETWEEN RETURN SCANS

FLIGHT RESPONSE TO 2 FULL MLS SCANS (ROLL AXIS)

Flight response and jitter are shown for a smaller time window covering two complete MLS scans.

Unlike the analytical time history response, the flight time history does not continue to rise until the return scan. The ACS, which was not modeled in the analytical simulation, will bring the spacecraft back when it responds too much in one direction. Jitter is relatively unaffected by the ACS since it primarily affects rigid body response. As discussed in chart 106, rigid body response during the tracking portion of the scan generates a maximum of 0.2 arcseconds of jitter.



UARS JITTER STUDY

FLIGHT RESPONSE TO 2 FULL MLS SCANS 117

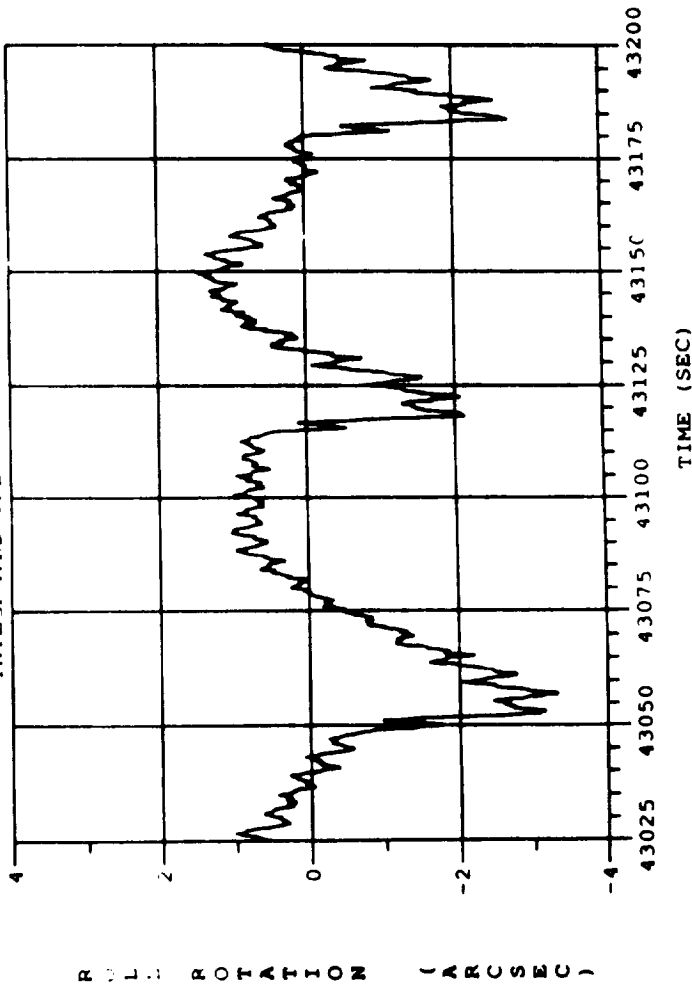
- S/A drive shutdown with S/A positioned at 278°
- MLS scanning
- HGA tracking
- All other instruments off

Time History

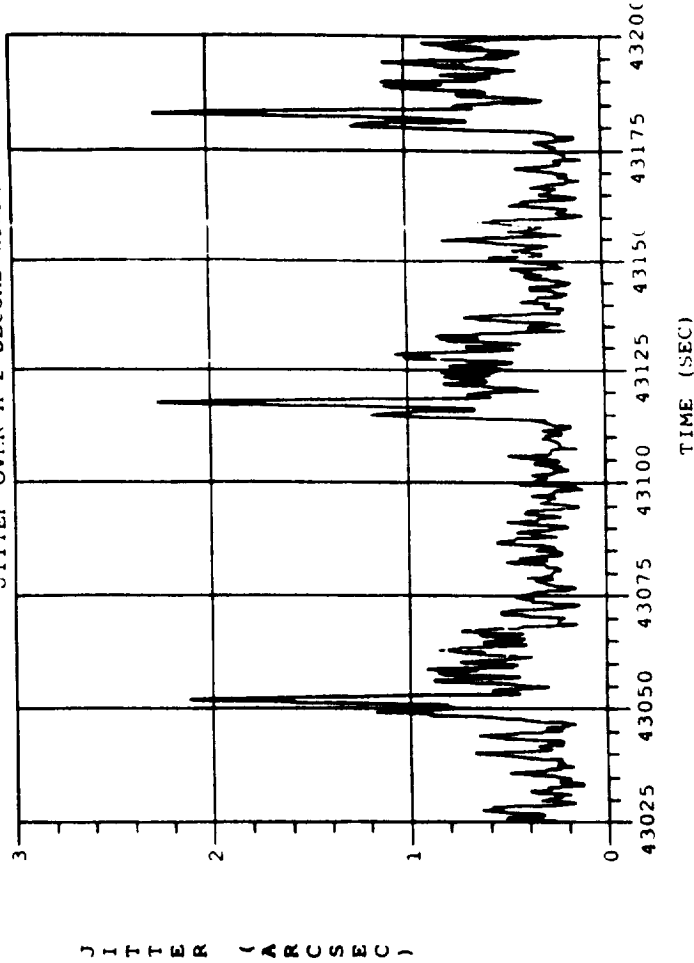
ROLL AXIS

Jitter

LAY 361 UARS ROLL GYRO ON ORBIT DATA
INTEGRATED UNBIASED DATA VIA +/-50 SEC WINDOW



LAY 361 UARS ROLL GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



0.25 HZ MODE DOMINATES RESPONSE

MLS JITTER CORRELATION (0.2% ANALYTICAL DAMPING)

Flight and analytical jitter assuming 0.2% critical damping in all modes are compared. During return scans, when rigid body motion dominates the response, analytical jitter exceeds flight jitter by 2.5 to 2.0 arcseconds. Between return scans, when motion from flexible modes dominate the response, analytical jitter exceeds flight jitter by approximately a factor of three.



UARS JITTER STUDY

MLS JITTER CORRELATION

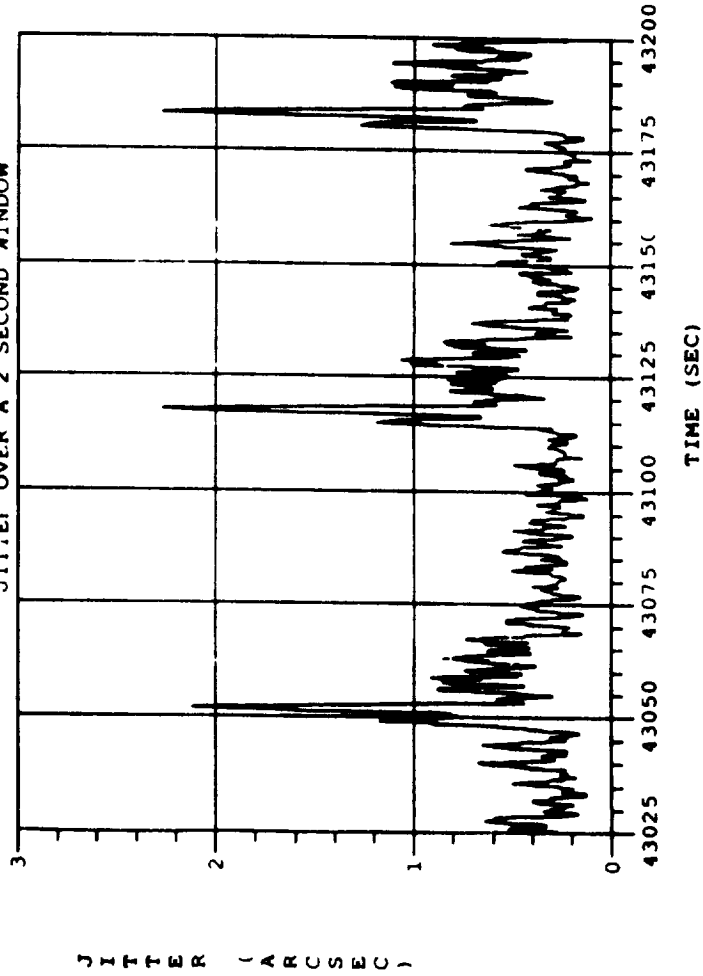
119

ROLL AXIS

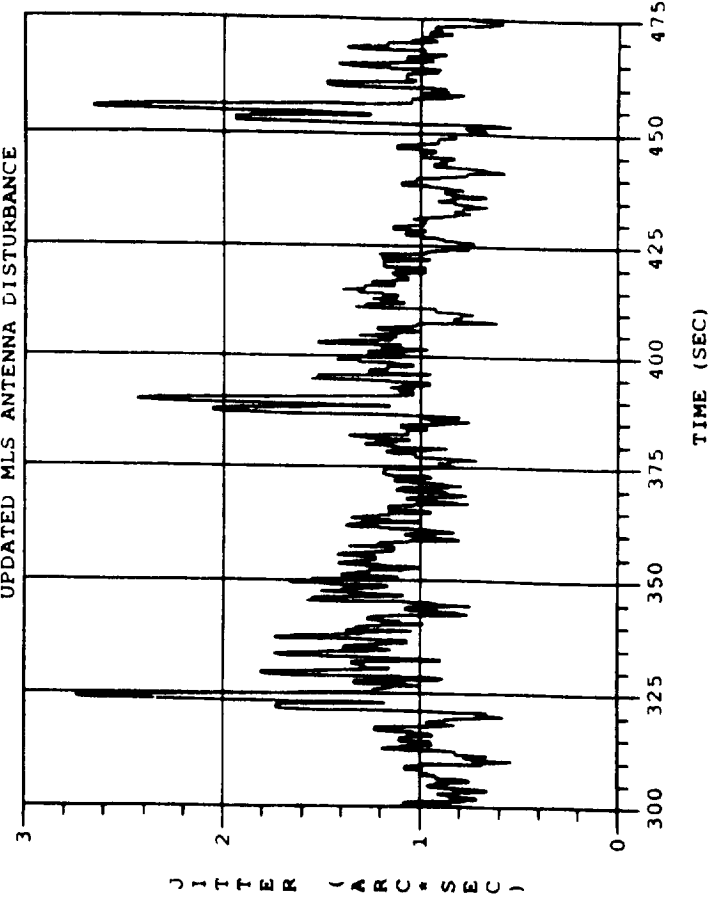
FLIGHT

Analytical (0.2% damping)

DAY 361 UARS ROLL GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



MMS 4876 ROLL JITTER OVER 2 SEC WINDOW
UPDATED MLS ANTENNA DISTURBANCE



ANALYTICAL PREDICTION EXCEEDS FLIGHT DATA
BY A FACTOR OF 3 BETWEEN RETURN SCANS

ANALYTICAL RESPONSE TO THE MLS DISTURBANCE (MEASURED DAMPING)

The MLS disturbance analysis was updated based on the measured flight damping values obtained with ERA. Measured flight damping for the flatwise bending mode was 2.8%. Damping measurements of 0.7% and 0.5% were obtained for modes at 0.98 Hz and 1.13 Hz respectively. These modes are believed to be ZEPS bending and the second solar array flatwise mode.

In the response shown, 2.8% critical damping was used for flatwise bending while 0.5% damping was used for the remainder of the modes below 4 Hz. Modes above 4 Hz were ignored since their response will be filtered out by the gyros.

The return scan is dominated by rigid body response while flexible motion dominates the tracking portion of the scan. Consequently, increasing damping from 0.2 % reduces jitter to a much greater degree for tracking than for the return scan.



UARS JITTER STUDY

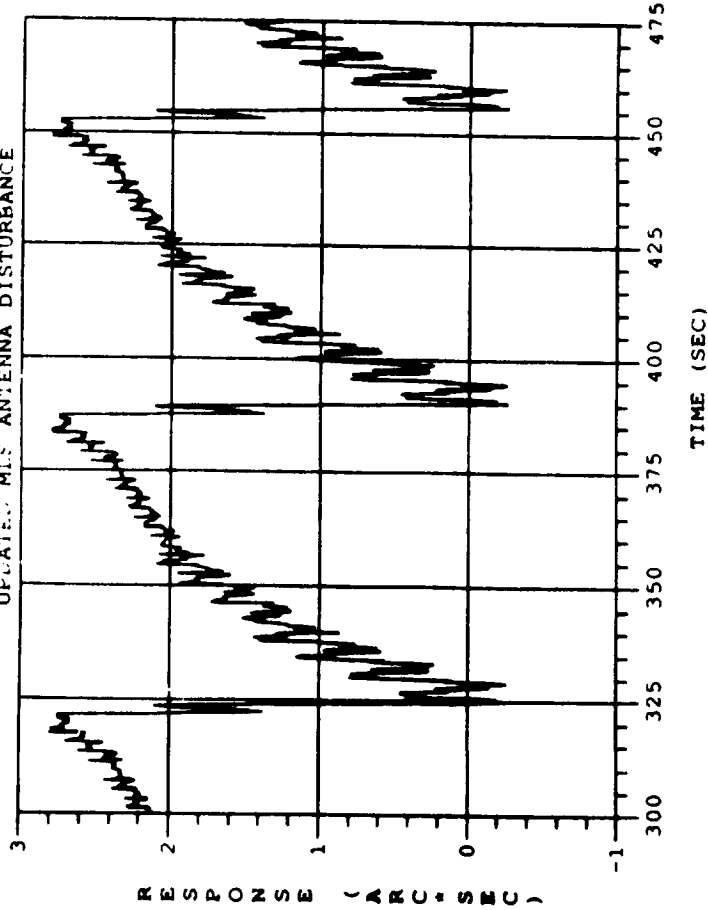
ANALYTICAL RESPONSE TO MLS DISTURBANCE 121

- **MEASURED** Flight Damping
- 2.8% Flatwise mode
- 0.5% All other modes < 4 Hz

ROLL AXIS

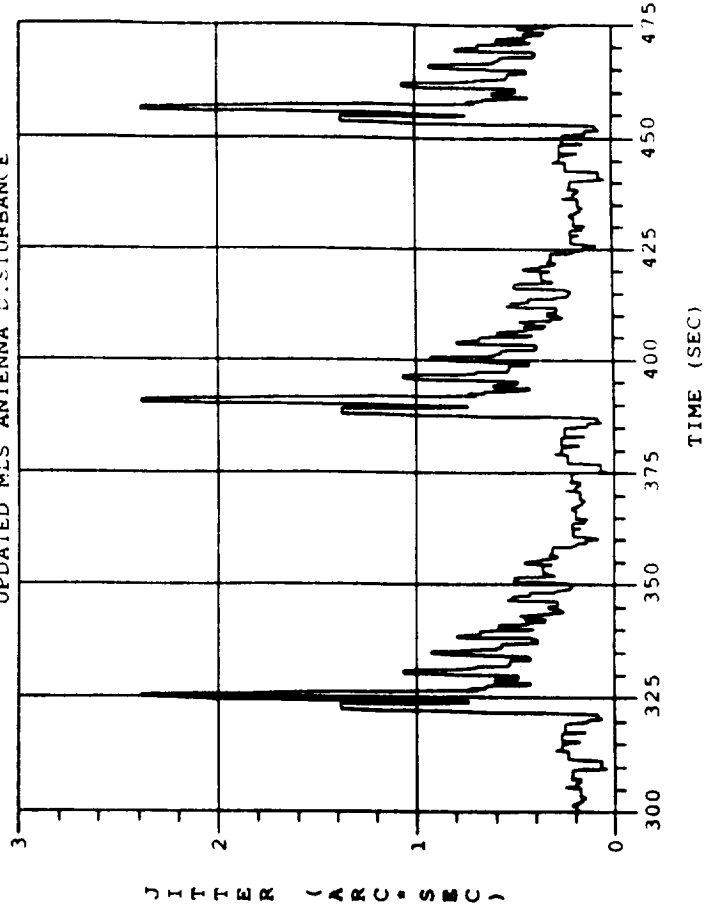
Time History

MMS 4816 ROLL RESPONSE S/A 270 DEG
UPDATED MLS ANTENNA DISTURBANCE



Jitter

MMS 4876 ROLL JITTER OVER 2 SEC WINDOW
UPDATED MLS ANTENNA DISTURBANCE



JITTER BETWEEN RETURN SCANS REDUCED TO
0.4 ARCSEC WITH 2% DAMPING

MLS JITTER CORRELATION (MEASURED DAMPING)

Good correlation exists between the analytical prediction and flight jitter. For the two return pulses, the analytical prediction exceeds flight by 17 percent (1.4 to 1.2 arcseconds) and 9 percent (2.4 to 2.2 arcseconds), respectively. Immediately after the return pulses when MLS begins to track, both the flight and analytic prediction peak at approximately 1 arcsecond. Peak jitter then tends to decrease further into the scan. Within the last 35 seconds before the next return scan, flight jitter does increase to a level not predicted with the analytic model. The jitter increase is due to an increase in the 0.25 Hz response and may be due to the ACS (not included in the analytical model). Spacecraft rigid body motion induced by the ACS will tend to excite the 0.25 Hz mode because of the solar array C.G offset. Other outside disturbances may also contribute to increase in flight jitter.



UARS JITTER STUDY

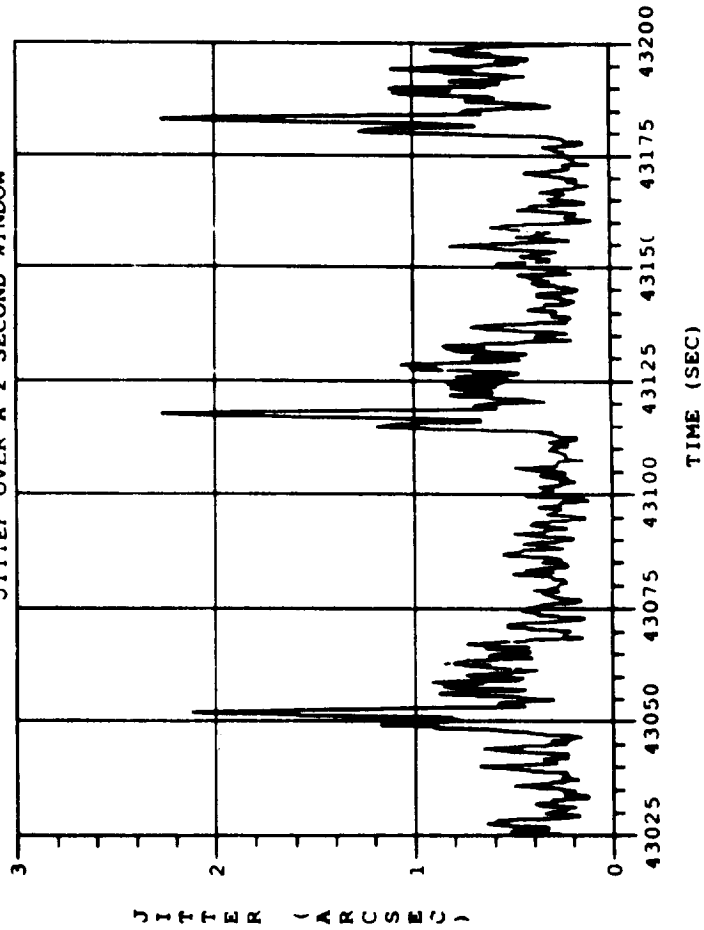
MLS JITTER CORRELATION

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ROLL AXIS

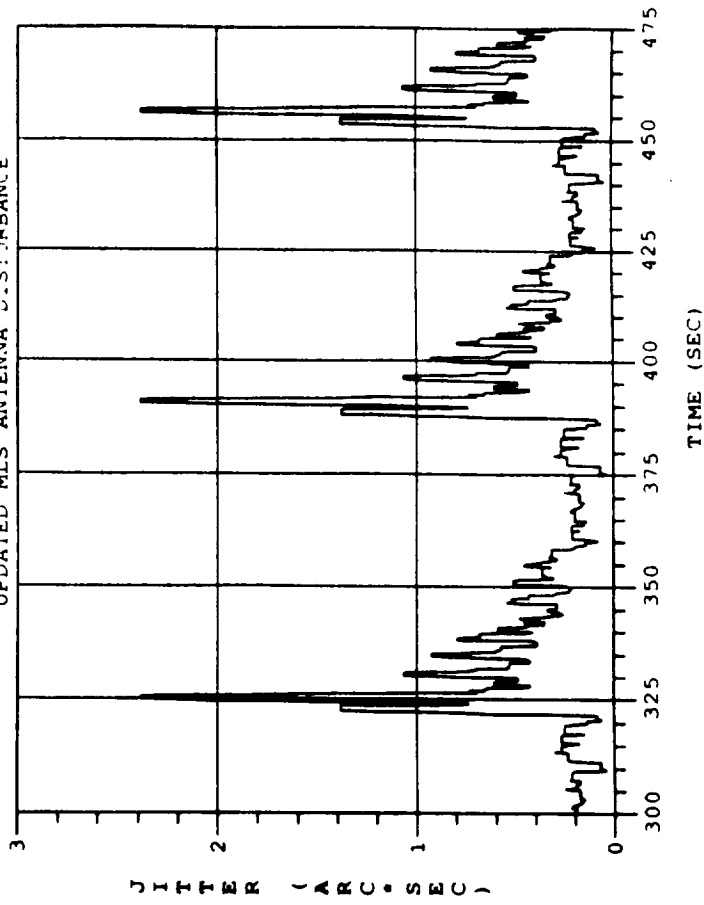
FLIGHT

DAY 301 UARS ROLL GYRO ON ORBIT DATA
JITTER OVER A 2 SECOND WINDOW



Analytical (Measured damping)

MMS 4876 ROLL JITTER OVER A 2 SEC WINDOW
UPDATED MLS ANTENNA DISTURBANCE



EXCELLENT CORRELATION WITH FLIGHT JITTER

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POWER SPECTRAL DENSITY (PSD)
CORRELATION OF MLS DISTURBANCE

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PSD CORRELATION OF MLS DISTURBANCE

The power spectral density (PSD) of an analytical time history containing five MLS scans was generated using IDEAS-TEST. The analysis assumed 2.8% damping for the flatwise mode and 0.5% damping for the remaining modes below 4 Hz. Modes above 4 Hz were excluded since their response will be filtered out by the gyros. The PSD was calculated using a Hanning window, 200 spectral lines, and a 0.128 second time increment between data points.

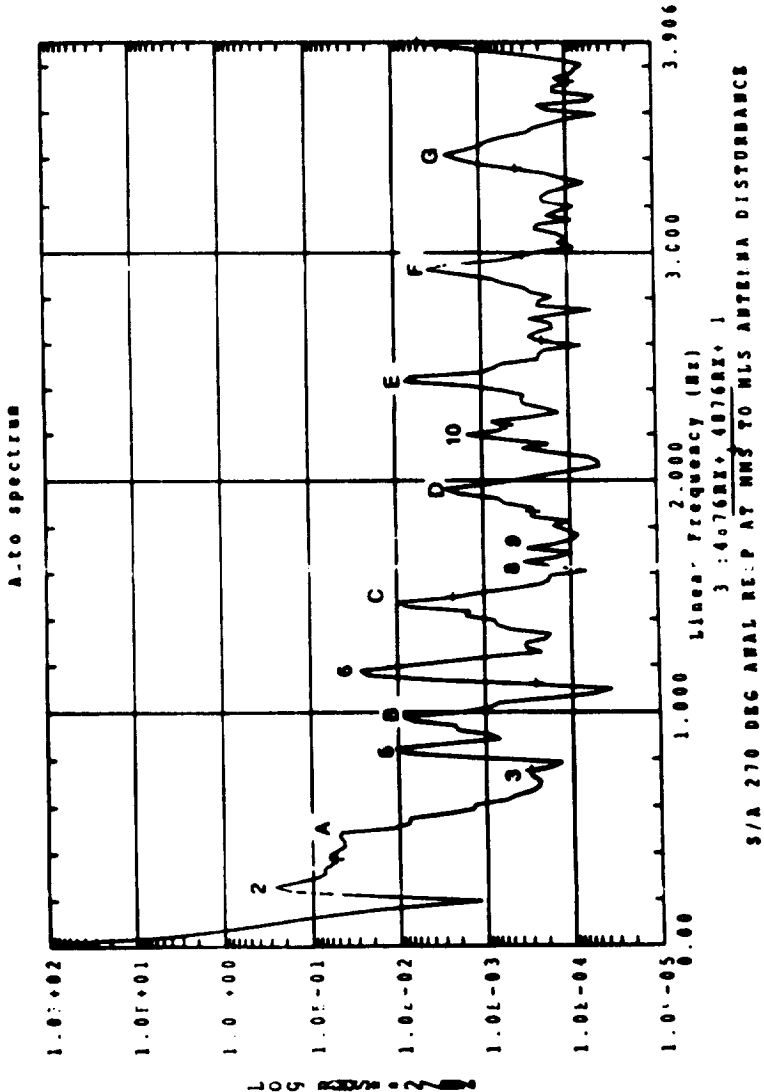
Peaks labeled with numbers correspond to modes excited by the disturbance. Peaks labeled with letters have no corresponding analytical modes. These peaks, as seen in the next chart, are due to the frequency content of the forcing function.



ANALYTICAL PSD

- PSD generated from 1) time history containing 5 MLS scans
2) Measured flight damping
3) 0.128 second time increment between data points

PSD



Analytical Frequencies

MODE	FREQ (HZ)	DESCRIPTION
1	0.231	S/A 1ST EDGEWISE BENDING (IN Z)
.. 2	0.249	S/A 1ST FLATWISE BENDING (IN X)
.. 3	0.718	S/A 1ST TORSION IN Y
4	0.795	ZEPS BOOM 1ST BENDING IN X
.. 5	0.831	ZEPS BOOM 1ST BENDING IN Y
.. 6	1.17	S/A 2ND FLATWISE BENDING
7	1.19	S/A SUPPORT TUBES
.. 8	1.70	SSPP ROTATION ABOUT Y (ALPHA)
.. 9	1.82	SSPP ROTATION ABOUT X (BETA)
..10	2.17	S/A 3RD FLATWISE BENDING
11	2.35	ZEPS 1ST TORSION ABOUT Z
12	2.67	S/A 2ND TORSION ABOUT Y
13	3.50	HRDI TEL TORSION ABOUT Z (AZIM.)

** Excited by MLS disturbance

A-G: No corresponding analytical mode

SOME PEAKS IN PSD OCCUR AT NON-RESONANT FREQUENCIES

FFT OF MLS TORQUE PROFILE

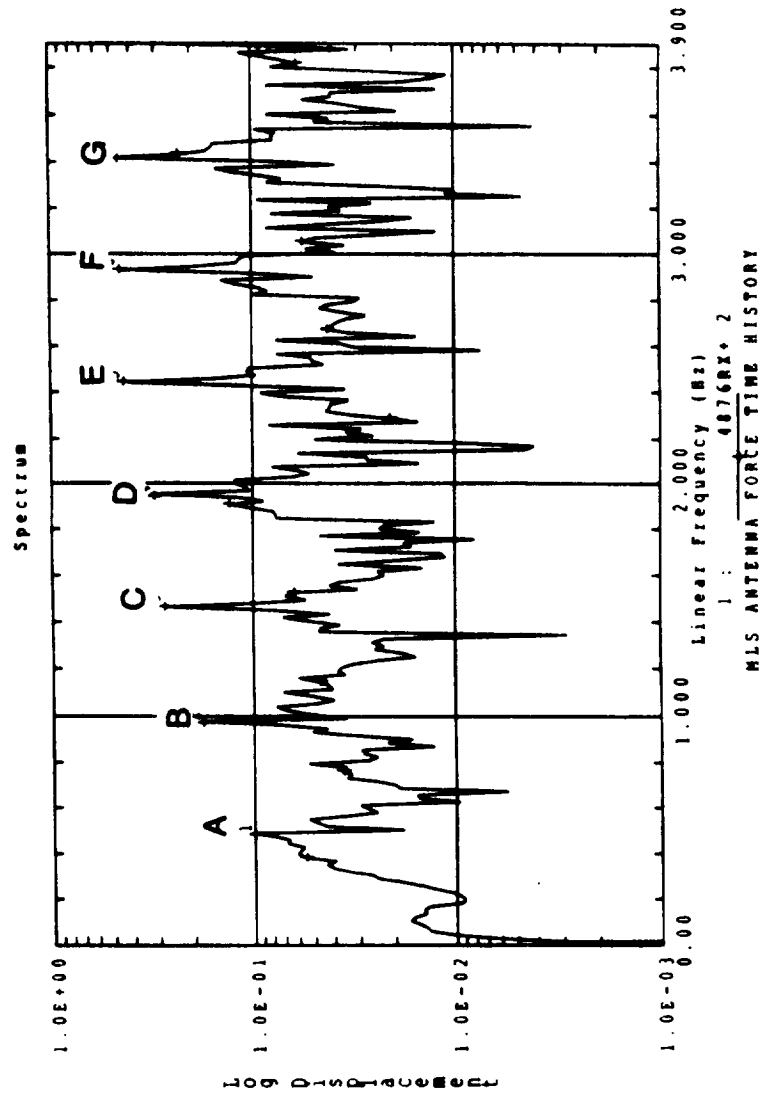
An FFT analysis was performed on the torque profile of one MLS scan. The non-resonant peaks of the analytical PSD coincide with the harmonics of the disturbance. Therefore, the non-resonant peaks are due to the frequency content of the disturbance.

The 0.48 Hz fundamental harmonic is caused by the torque pulses being applied every 2.048 seconds.



FFT OF MLS TORQUE PROFILE

FFI



Non-resonant peaks in
analytical PSD

- | | |
|---|---------|
| A | 0.48 Hz |
| B | 0.96 Hz |
| C | 1.47 Hz |
| D | 1.96 Hz |
| E | 2.45 Hz |
| F | 2.94 Hz |
| G | 3.41 Hz |

HARMONICS COINCIDE WITH NON-RESONANT PEAKS IN PSD

FLIGHT PSD (10 MLS SCAN TIME HISTORY)

The consistency of the flight PSD was desired to be known. Therefore, two flight PSDs were generated each containing five MLS scans. The difference in the two time histories is primarily due to the ACS affecting the amount of rigid body motion.

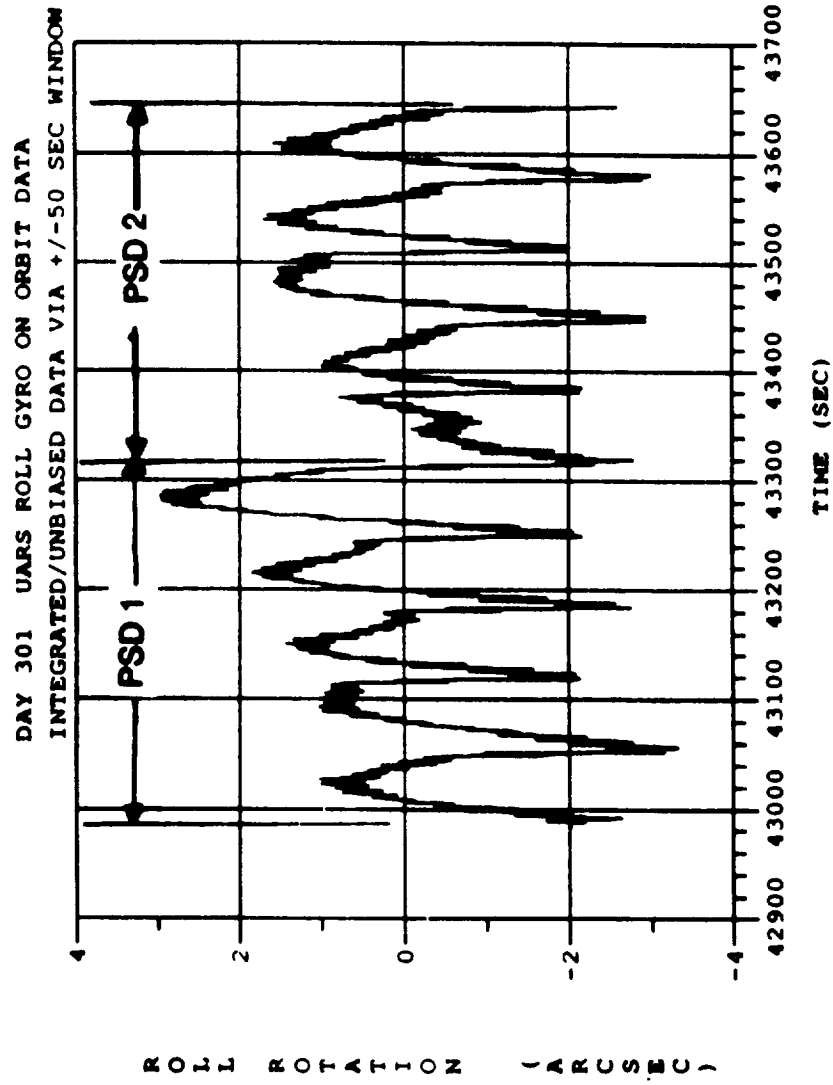


UARS JITTER STUDY

FLIGHT PSD

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FLIGHT TIME HISTORY



- S/A drive shutdown
- S/A positioned at 278°
- MLS scanning
- HGA tracking
- All other instruments off

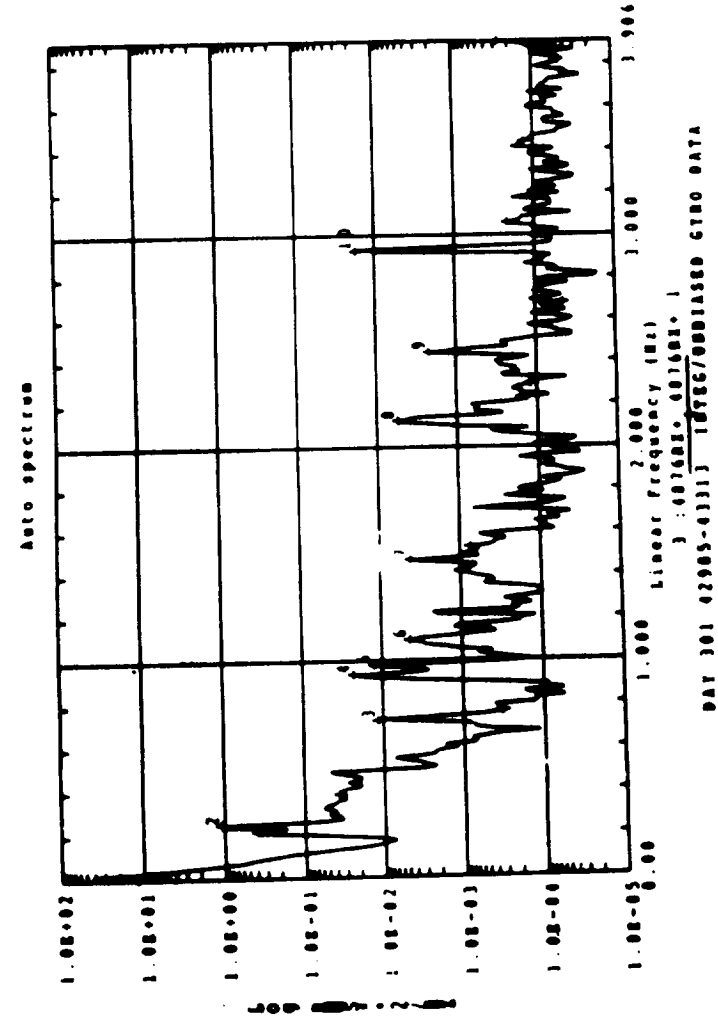
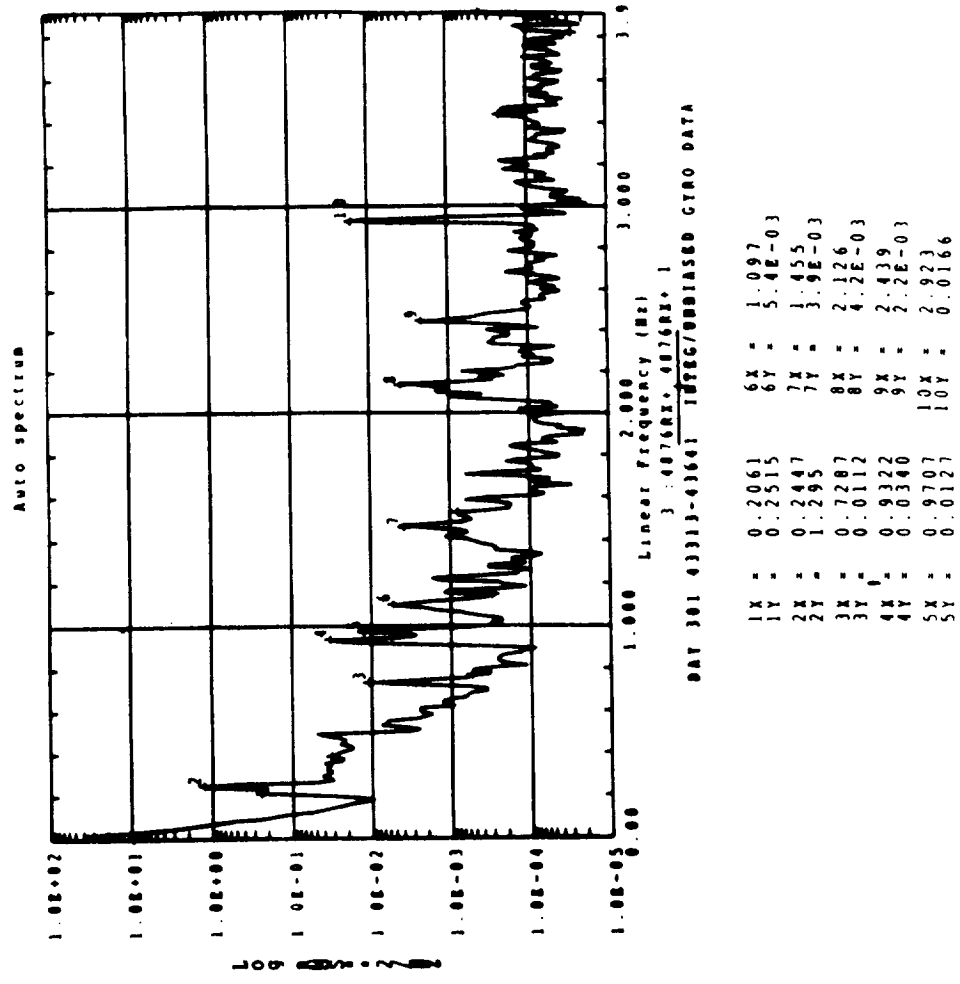
PSD CALCULATED FOR 2 TIME HISTORIES EACH
CONTAINING 5 COMPLETE MLS SCANS

FLIGHT PSD (COMPARISON OF 2 FLIGHT PSDS)

Peaks for the two different PSDs are tagged. X corresponds to frequency and Y corresponds to magnitude. The frequencies and magnitudes are practically identical for the two PSDs.



FLIGHT PSD

PSD OF FIRST 5 SCANSPSD OF SECOND 5 SCANS

PSD FOR 2 DIFFERENT TIME PERIODS ARE VIRTUALLY IDENTICAL

PSD CORRELATION (5 MLS SCANS)

The flight and analytical PSDs are compared. Peaks labeled with letters result from the frequency content of the forcing function. Peaks labeled with numbers correspond to modes excited by the disturbance.

There is a small peak at 0.217 Hz (#1) which is believed to correspond to the solar array edgewise mode. This mode was also detected at the 90 degree position with a PSD analysis of the Day 128 roll gyro data (performed by Stan Woodward of NASA Langley). The flatwise mode (#2) has the largest response for both the analytical and flight data.

There is some question as to whether flight mode #3 is really solar array torsion. It was identified as such because it is the closest analytical mode. However, there is no known reason why MLS would excite solar array torsion to such a strong degree. It was originally assumed that flight solar array torsion (#3) and ZEPS bending in Y (#5) were switched. Data from Day 281 solar array shutdown shown in chart 138 seems to indicate that ZEPS bending occurs near 1 Hz.

Identification of the higher order flight modes is based strictly on matching the PSD spikes to the nearest analytical frequency. Matching PSD magnitudes may lead to errors since the amount of damping for the higher order modes is unknown.

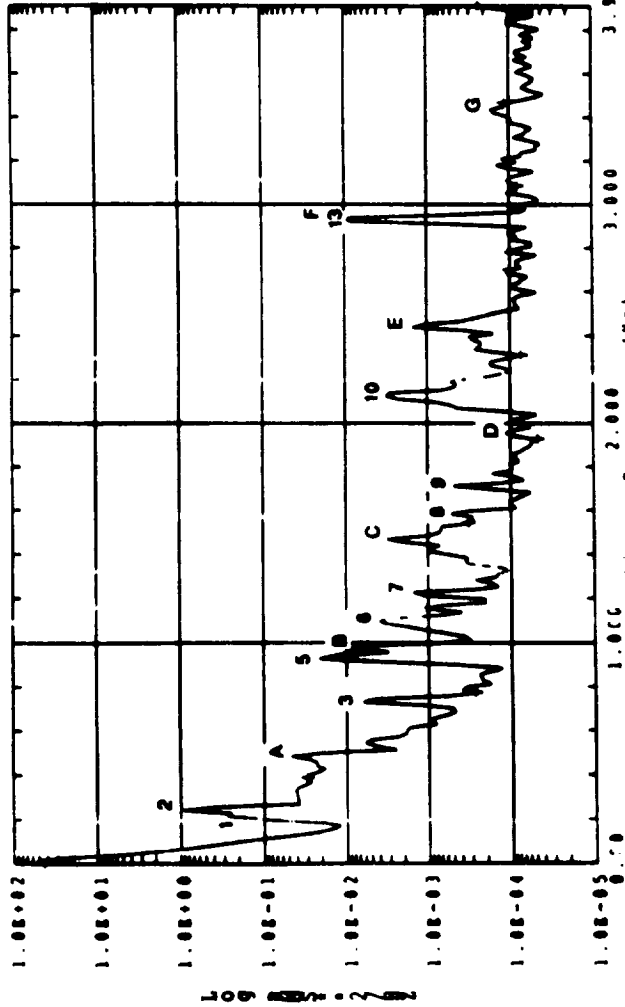
The flight mode at 2.93 Hz (#13) coincides with a forcing frequency harmonic (F). A strong 2.93 Hz response exists even when MLS is not operating as in the Day 281 data.



PSD CORRELATION

FLIGHT PSD

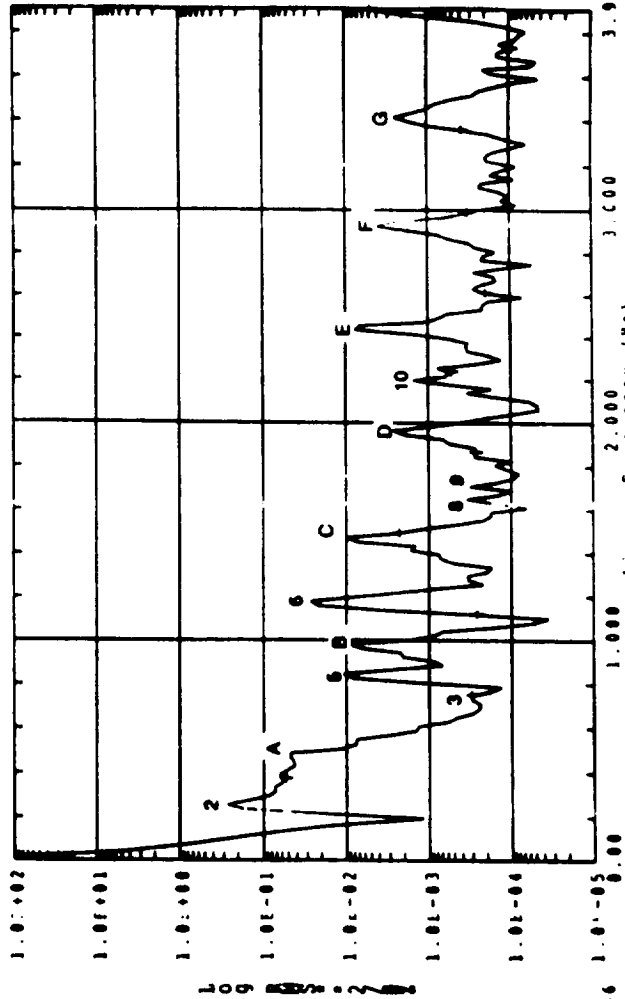
Auto spectrum



DAY 30: 42985-43641 18965/UNDIASED gyro DATA

ANALYTICAL PSD

A-to spectrum



S/A 270 DEG ANAL REP AT 445 TO MLS ANTENNA DISTURBANCE

- A-G : Based on frequency content of forcing function
- 1-13: Spacecraft modes

PSD BASED ON MLS EXCITATION ONLY

PSD CORRELATION (BETWEEN RETURN SCANS)

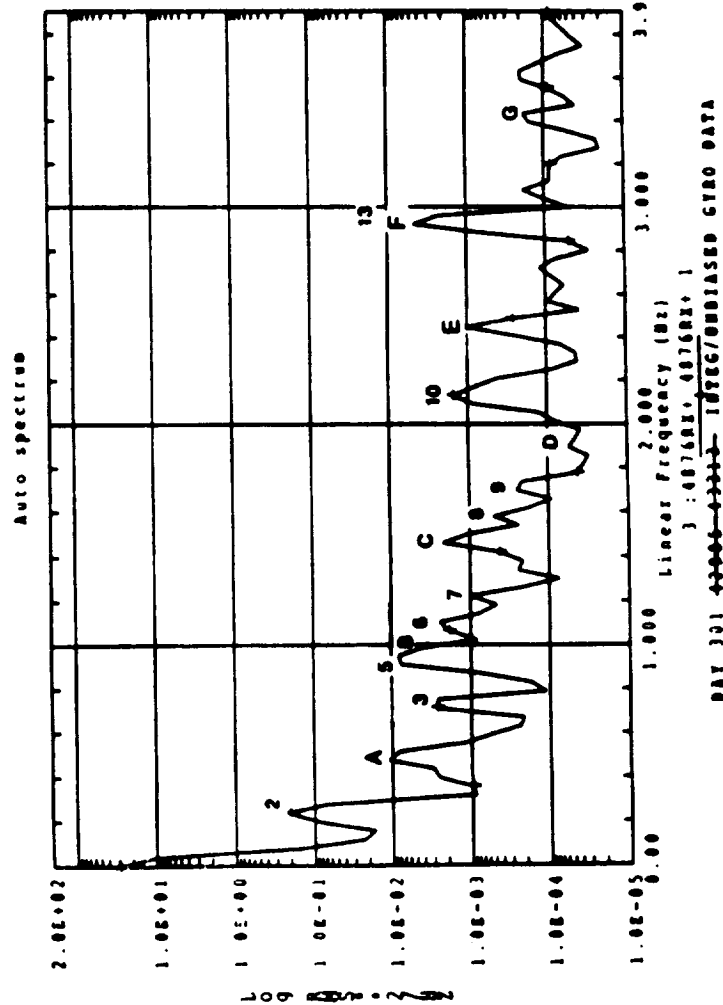
Analytic and flight PSDs were generated from the response during MLS tracking only. The return scan was removed from the PSD analysis. Because of a fewer number of data points, only 100 spectral lines were used for the PSD analysis. Consequently, closely spaced peaks from the previous chart (such as 5 and B) are combined into only one peak.



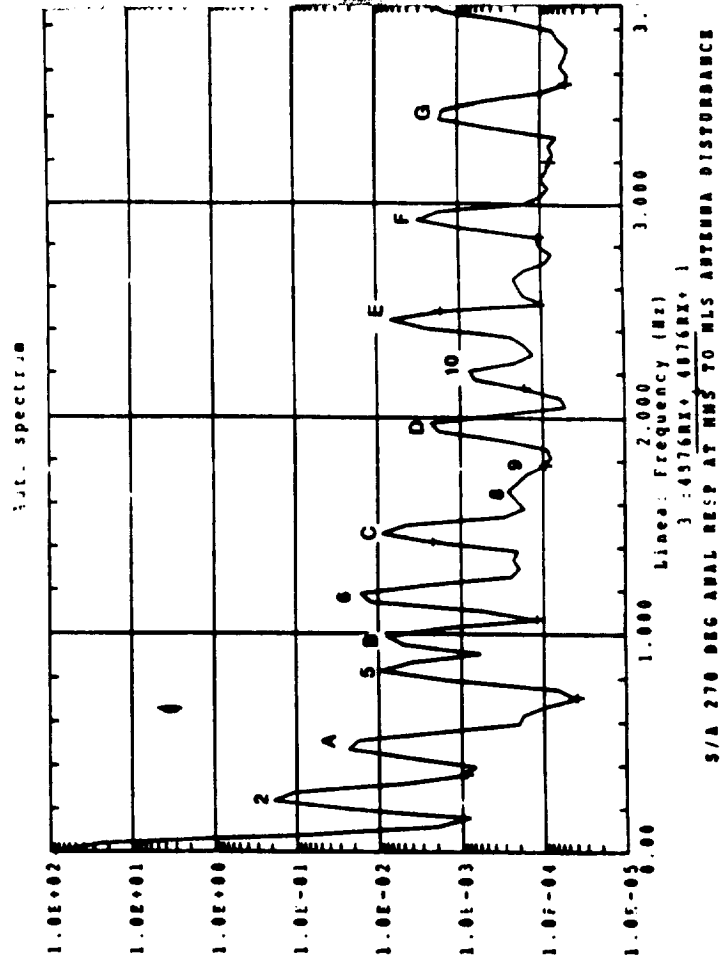
PSD CORRELATION

- PSDs were generated from a 45 second time window between 2 return scans with 0.128 second time increment between data points

Flight PSD



Analytical PSD



- A-G: Based on frequency content of forcing function
- 1-13: Spacecraft modes

PSD BASED ON FREQUENCY CONTENT DURING MLS TRACKING ONLY

DAY 281 SOLAR ARRAY DRIVE SHUTDOWN

On Day 281, a planned test of the UARS solar array drive was performed in which the drive was turned on for roughly 20 seconds. The solar array was parked at 275 degrees at the start of the test. In this position, the solar array flatwise mode acts about roll and the edgewise mode acts about yaw.

The spacecraft response as measured by the gyros is shown. Immediately after the solar array drive is started, a 0.22 Hz response is seen in roll and yaw. The mode is believed to be the solar array edgewise mode since the magnitude of the yaw response is greater than roll. In addition, the response makes physical sense because starting the drive will give the solar array velocity in the edgewise direction exciting the mode.

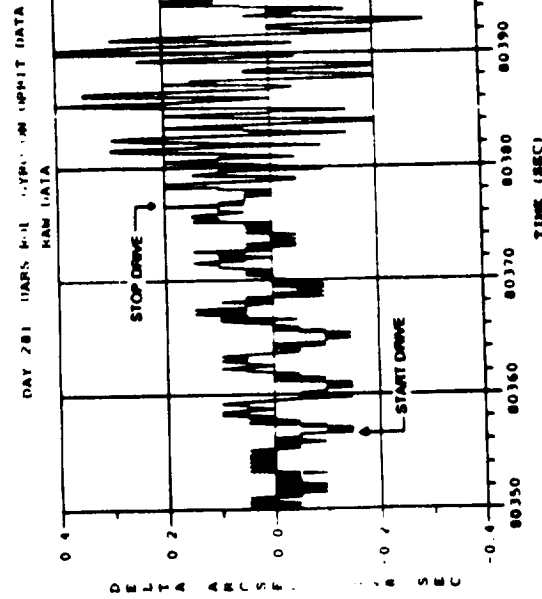
After the solar array drive shutdown, a 0.95 Hz mode dominates the response in roll and pitch. There is some speculation at GE Astro that the 0.95 Hz mode is solar array torsion since 1) the mode should be excited upon shutdown and 2) the mode acts about the spacecraft pitch axis. However, it is difficult to explain why the mode excites roll to a greater magnitude than pitch. Another theory is that the 0.95 Hz mode is ZEPS bending. ZEPS bending in X acts about the pitch axis while ZEPS bending in Y acts about the roll axis. ZEPS could be bending in a direction that will be seen in both roll and pitch. Furthermore, ZEPS bending does not act about the yaw axis and the 0.95 Hz response does not appear in the yaw gyro data.



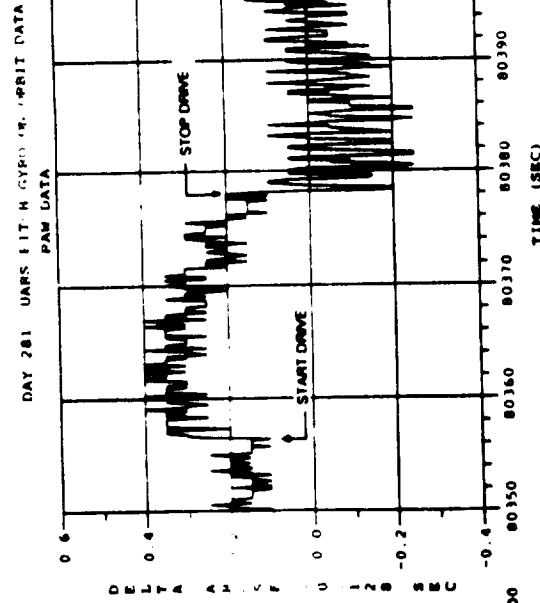
UARS JITTER STUDY

DAY 281 SOLAR ARRAY DRIVE SHUTDOWN 139

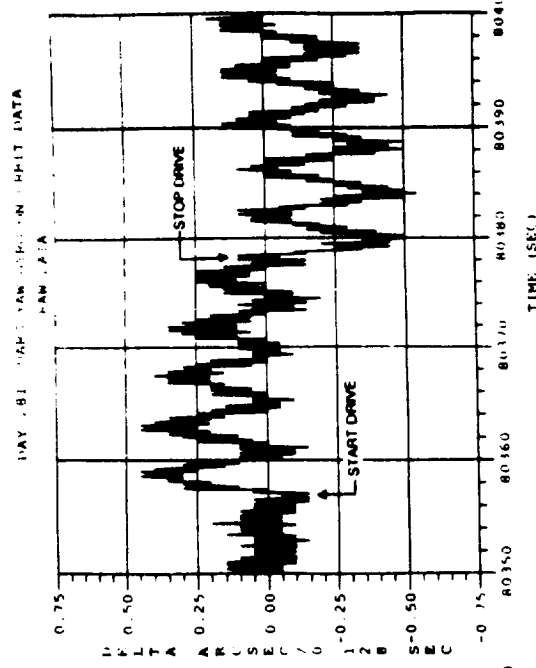
ROLL GYRO



PITCH GYRO



YAW GYRO



- 0.22 Hz response in roll and yaw after the drive is started
- 0.95 Hz response in roll and pitch after the drive is stopped
- 2.93 Hz response in yaw riding on top of the 0.22 Hz signal

0.95 HZ MODE BELIEVED TO BE ZEPS BENDING

MODE IDENTIFICATION BASED ON PSD CORRELATION

A summary of the different measured flight modes at the 270 degree solar array position is presented. There is high confidence in the modal frequencies identified for the edgewise and flatwise solar array modes. Less confidence is placed in the mode descriptions identified for the higher order flight frequencies. These modes are difficult to identify because the spacecraft response is only measured at the MACS module. Additional instrumentation would significantly improve the ability to identify these modes.



UARS JITTER STUDY

MODE IDENTIFICATION BASED ON PSD CORRELATION 141

Solar array position 270 °

MODE #	MODE DESCRIPTION	ANALYTICAL FREQ (HZ)	DAY 301 PSD FLIGHT FREQ(HZ)	DAY 128 ERA FLIGHT FREQ(HZ)
1	S/A 1ST EDGEWISE BENDING	0.231	0.217	
2	S/A 1ST FLATWISE BENDING	0.249	0.239	0.235
3	S/A 1ST TORSION IN Y	0.718	0.723	0.752
4	ZEPS BOOM 1ST BENDING IN X	0.795		
5	ZEPS BOOM 1ST BENDING IN Y	0.831	0.927	0.958
6	S/A 2ND FLATWISE BENDING	1.17	1.09	1.03
7	S/A SUPPORT TUBES	1.19	1.22	
8	SSPP ROTATION ABOUT Y (ALPHA)	1.70	1.58	1.47
9	SSPP ROTATION ABOUT X (BETA)	1.82	1.71	
10	S/A 3RD FLATWISE BENDING	2.17	2.13	2.13
11	ZEPS 1ST TORSION ABOUT Z	2.35		
12	S/A 2ND TORSION ABOUT Y	2.67		
13	HRDI TEL TORSION ABOUT Z (AZIMUTH)	3.50	2.93	2.93
14	HRDI TEL TORSION ABOUT Y (ZENITH)	3.56		
15	S/A 4TH FLATWISE BENDING	3.83		
16	S/A 3RD TORSION ABOUT Y	4.41		

DIFFICULT TO IDENTIFY FLIGHT MODES WITH ONLY GYROS

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UARS JITTER STUDY

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HGA AND SSPP JITTER
DAY 266 DATA

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UARS JITTER STUDY

DAY 266 FLIGHT DATA ANALYSIS

On Day 266 (June 3, 1992), the HGA and SSPP both perform slew maneuvers. In addition, the reaction wheels move to a safe hold mode. Flight data presented in the following charts illustrate the instrument position during the maneuvers as well as the spacecraft response to these maneuvers.

As seen in charts 158 through 162, the response to these maneuvers is primarily rigid body and occurs over a time span greater than 100 seconds. Data averaging with only a 100 second window distorts the response. A larger window was required to reduce the distortion due to the data averaging technique.

No analytical correlation was performed since the response does not include much flexible motion and is primarily rigid body.



DAY 266 FLIGHT DATA ANALYSIS

- INSTRUMENT STATUS
 - S/A DRIVE OFF AND POSITIONED AT 278°
 - ALL INSTRUMENTS ARE OFF EXCEPT HGA AND SSPP
 - BOTH THE HGA AND SSPP PERFORM SLEW MANEUVERS
 - REACTION WHEELS GO INTO SAFE HOLD MODE
- FLIGHT DATA PROCESSING
 - SINCE MANEUVERS TAKE LONGER THAN 100 SECONDS, NEED TO USE LARGER WINDOW FOR FORWARD/BACKWARD DATA AVERAGING (+/- 500 SECONDS)
- SPACECRAFT RESPONSE AND JITTER FOR DIFFERENT DISTURBANCE EVENTS
 - HGA AND SSPP MANEUVERS
 - RWA SLOWDOWN
- RESPONSE PRIMARILY RIGID BODY - NO ANALYTICAL CORRELATION PERFORMED

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UARS JITTER STUDY

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DAY 266 INSTRUMENT STATUS

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UARS JITTER STUDY

HGA STATUS

The High Gain Antenna (HGA) subsystem has an antenna for open loop tracking of the TDRS satellites. UARS telemetry is transmitted to whichever TDRS satellite is visible (line of sight) and then relayed to the ground receiver. The antenna scans in two axes. About the alpha axis, which is always the same as the spacecraft pitch axis, the HGA tracks at a rate of 0.07 degrees per second. About the beta axis, which is always perpendicular to the alpha axis but depends on alpha, the maximum tracking rate is 0.012 degrees per second.

When the antenna loses track of a TDRS it rewinds to the next expected acquisition position and waits. The maximum rewind rate for both the alpha and beta gimbals is 0.31 degrees per second.

The HGA alpha and beta positions are shown for a 2000 second time period on Day 266. Telemetry is downlinked every 4 UARS seconds for both telemetry points.



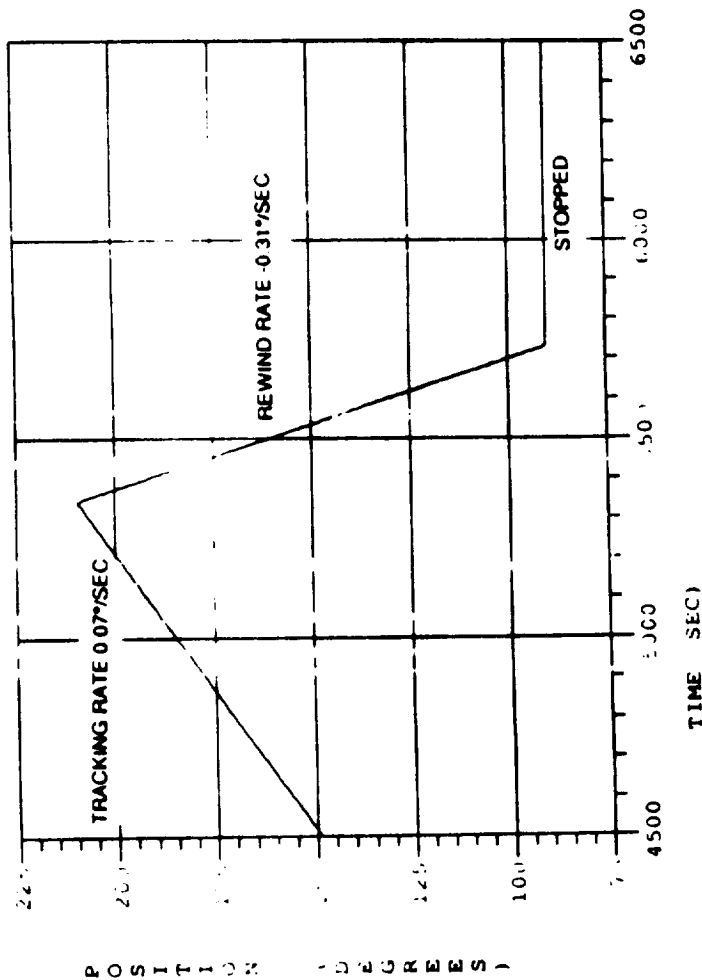
UARS JITTER STUDY

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DAY 266 HGA STATUS

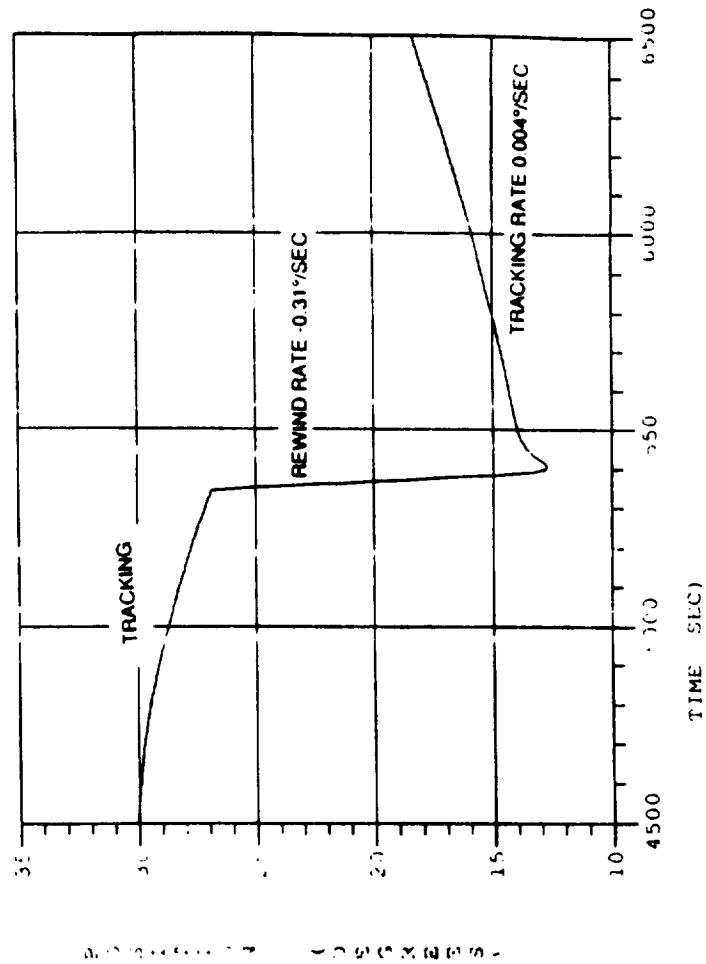
HGA ALPHA

DAY 266 HGA ALPHA MODE POSITION



HGA BETA

DAY 266 HGA BETA MODE POSITION



HGA BEGINS REWIND NEAR 5300 SECONDS

SSPP STATUS

The Solar Stellar Pointing Platform (SSPP) is a two axis gimballed platform. It has three instruments (ACRIM, SOLSTICE, and SUSIM) mounted on it. The platform can track (open or closed loop) the sun or any of twenty stars whose position coordinates have been loaded up to the on board computer. The SSPP alpha gimbal, which is always lined up with the spacecraft pitch axis, tracks at a rate of 0.062 degrees per second. The beta gimbal, which is always perpendicular to alpha axis but depends on alpha, does not track.

When the platform loses track of a target it rewinds to the next expected acquisition position and waits. The maximum rewind rate for the alpha and beta gimbals is 0.20 and 0.16 degrees per second, respectively.

The SSPP alpha and beta positions are shown for a 2000 second time period on Day 266. Telemetry is downlinked every 0.128 seconds.



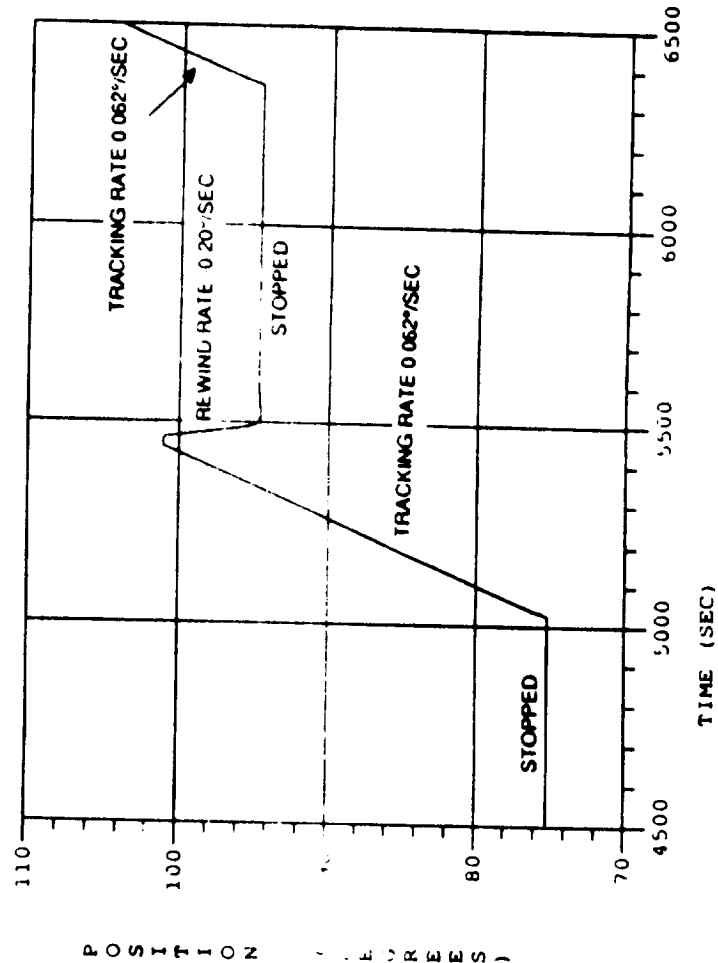
UARS JITTER STUDY

DAY 266 SSPP STATUS

151

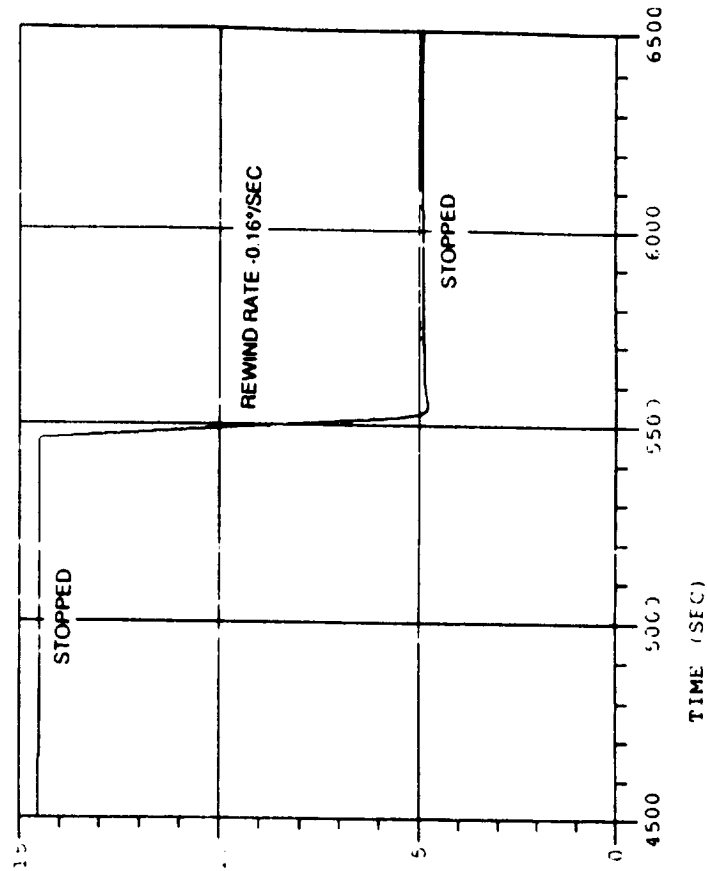
SSPP ALPHA

DAY 266 SSPP ALPHA ENCODER POSITION



SSPP BETA

DAY 266 SSPP BETA ENCODER POSITION



SSPP IN BOTH A TRACKING AND REWIND MODE

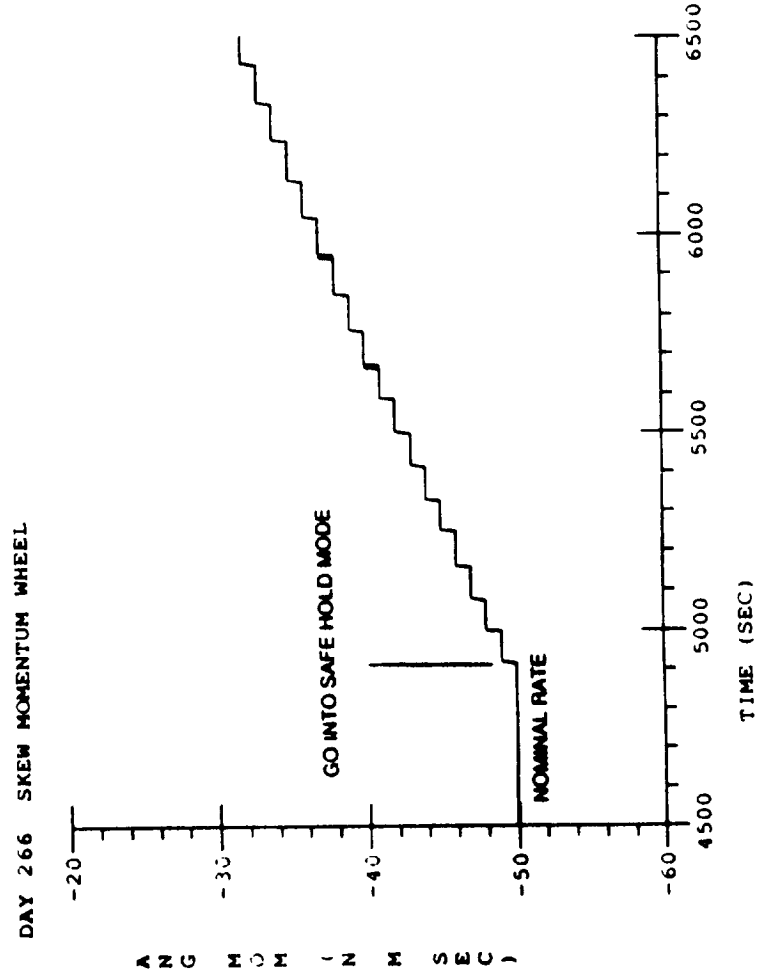
REACTION WHEEL STATUS

Reaction wheels are controlled by the Attitude Control System to counteract disturbances on board the spacecraft. UARS has four reaction wheels. Three of the reaction wheels act about the spacecraft roll, pitch, and yaw axes (X, Y, and Z). The fourth reaction wheel acts about a skew axis.

On Day 266 at 4900 seconds, all the reaction wheels begin to slow down on their way to a safe hold mode. Telemetry is downlinked every 4 UARS seconds.



RWA SKEW WHEEL



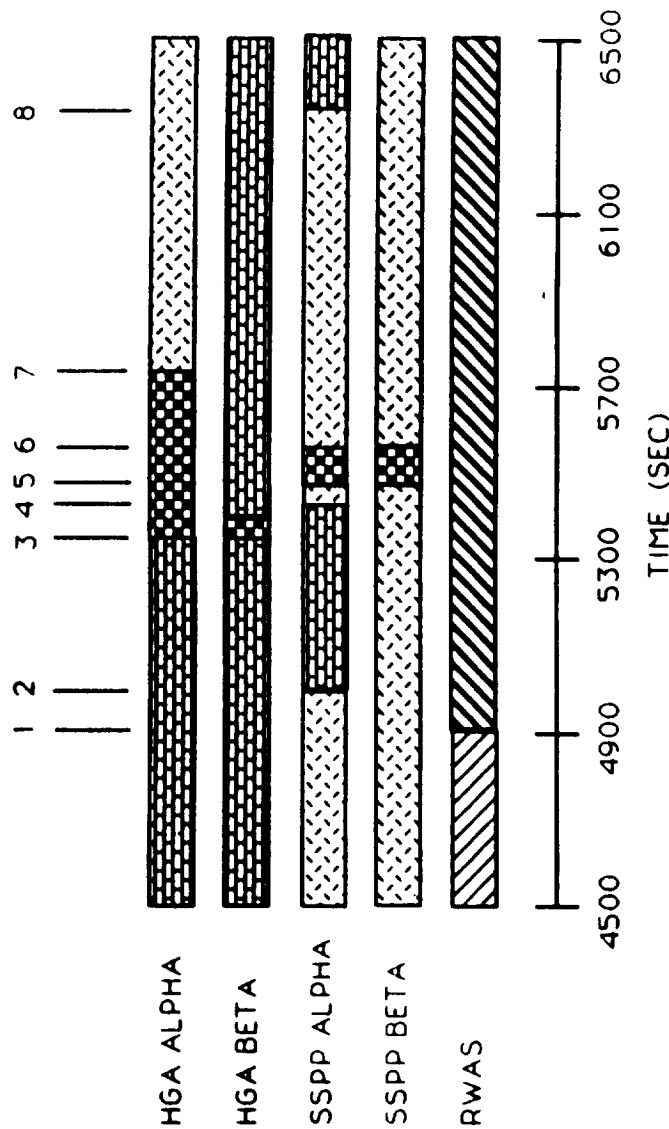
REMAINING RWAS SLOW DOWN AT SAME TIME

DAY 266 INSTRUMENT STATUS SUMMARY

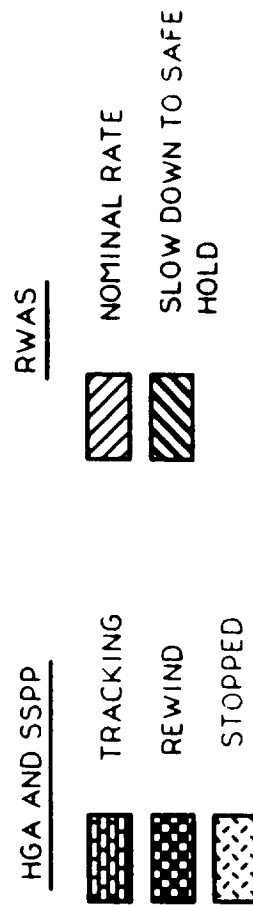
Eight time periods are highlighted in the instrument status summary. These eight time periods coincide with a large disturbance seen in the spacecraft response presented in following charts.



DAY 266 INSTRUMENT STATUS SUMMARY 155



Event	Time	Description
1	4910	RWA slowdown
2	5025	SSPP α start tracking
3	5342	HGA α & β start rewind
4	5436	SSPP α stop tracking
5	5462	SSPP α & β start rewind
6	5520	SSPP α & β stop rewind
7	5727	HGA α stop
8	6351	SSPP α start tracking



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UARS JITTER STUDY

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DAY 266 DATA PROCESSING

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DAY 266 DATA PROCESSING (100 SECOND WINDOW AVERAGING)

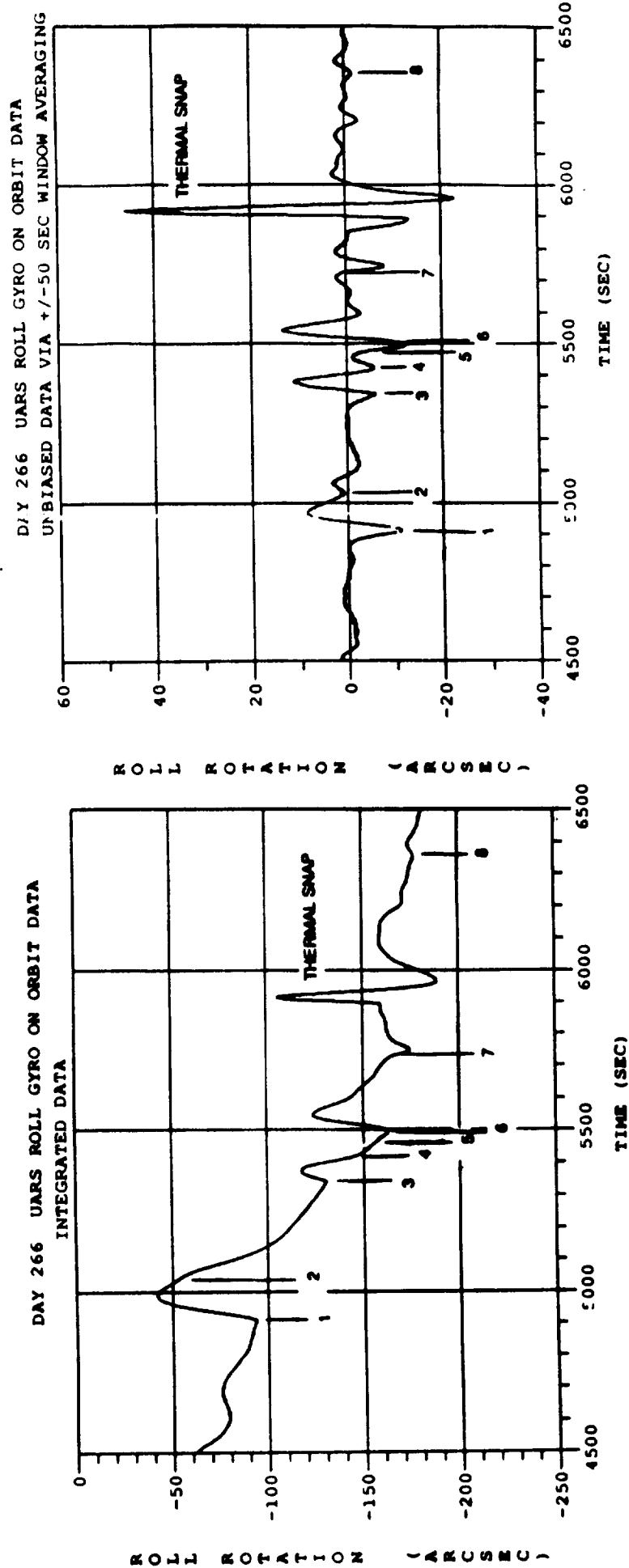
Gyro drift rate error creates the negative sloped bias in the Day 266 integrated data. To remove the bias, the data averaging technique is employed. For disturbances that occur within a small time window, data averaging using a 100 second window removes the bias without distorting the time history response. But for Day 266 disturbances which occur over a long time span and have large rigid body motion, distortion such as that for disturbance number 1 occur. In the data averaged response, a rotation of negative 10 arcseconds is seen immediately before the disturbance. The rotation is artificial, created by the data averaging process. The negative 10 arcsecond rotation is clearly not seen in the integrated data. A larger time window is required in order to not distort the time history response.



DAY 266 DATA PROCESSING

159

ROLL AXIS

DAY 266 INTEGRATED DATAFORWARD/BACKWARD AVERAGING (+50 SEC)

- DATA AVERAGING DISTORTS TIME HISTORIES
- DISTURBANCES OCCUR OVER A LARGER TIME SPAN THAN WINDOW

LARGER WINDOW REQUIRED FOR DATA AVERAGING

DAY 266 DATA PROCESSING (1000 SECOND WINDOW AVERAGING)

Using a 1000 second window, the drift rate error has been removed without distortion. The data averaged response follows the response of the integrated data. The artificial rotation before disturbances as seen previously with the 100 second window has disappeared.

The response to these disturbances is primarily rigid body. The response occurs over hundreds of seconds and results in relatively large rotations. The ACS can be seen to bring back the spacecraft when it has rotated too much in one direction (at 5000 seconds for example).



UARS JITTER STUDY

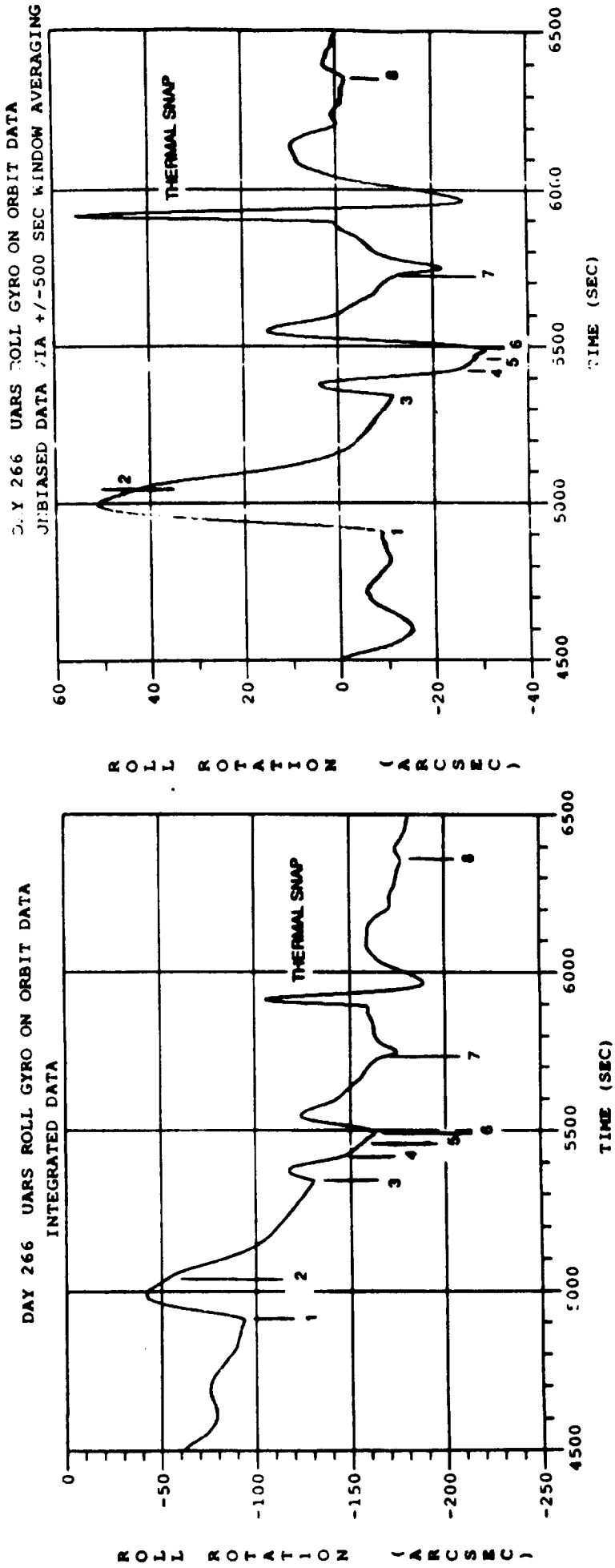
DAY 266 DATA PROCESSING

161

ROLL AXIS

DAY 266 INTEGRATED DATA

FORWARD/BACKWARD AVERAGING (± 500 SEC)



- TIME HISTORIES LESS DISTORTED WITH ± 500 SECOND WINDOW

SPACECRAFT RESPONSE IS MOSTLY RIGID BODY

DAY 266 PITCH AND YAW RESPONSE

The pitch and yaw response also show large rigid body motion due to the disturbances.

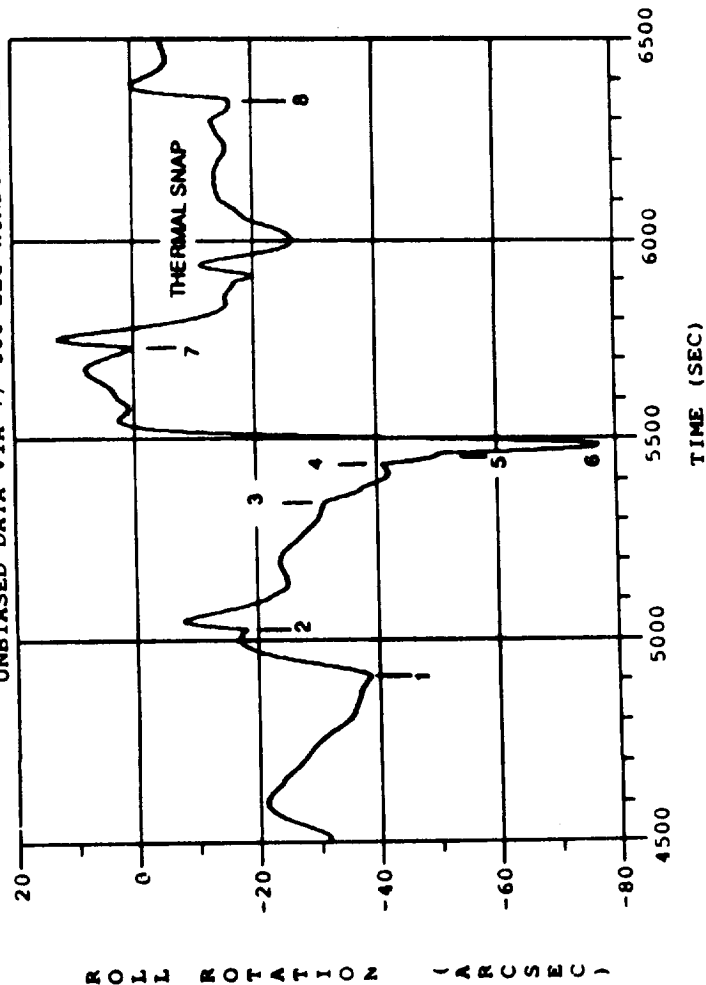


DAY 266 DATA PROCESSING

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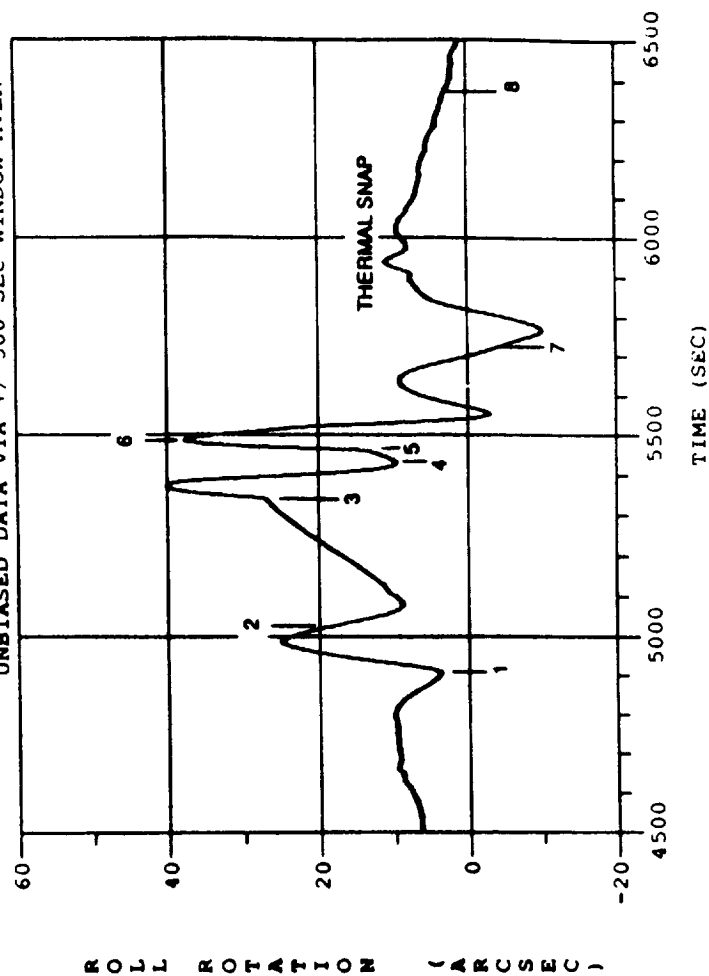
PITCH TIME HISTORY

DAY 301 UARS PITCH GYRO ON ORBIT DATA
UNBIASED DATA VIA +/-500 SEC WINDOW AVER



YAW TIME HISTORY

DAY 301 UARS YAW GYRO ON ORBIT DATA
UNBIASED DATA VIA +/-500 SEC WINDOW AVER



SPACECRAFT RESPONSE IS MOSTLY RIGID BODY

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UARS JITTER STUDY

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DAY 266 DISTURBANCE EVENTS

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164 DISTURBANCE EVENTS

DAY 266 RWA SLOWDOWN

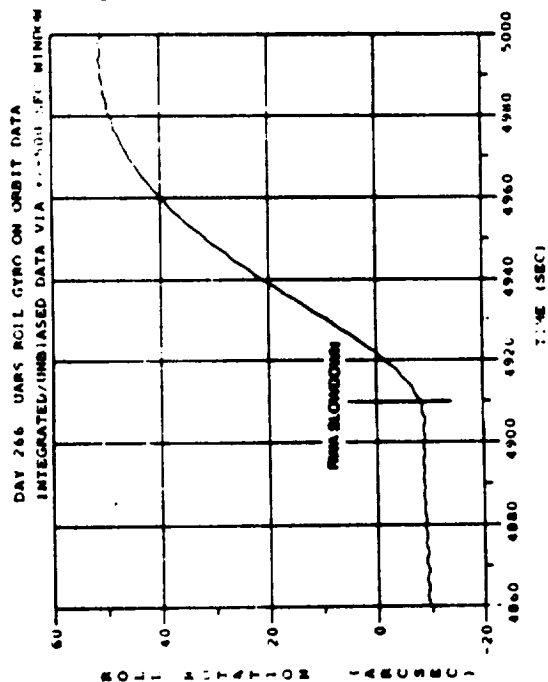
The spacecraft response in roll, pitch, and yaw for the RWA slowdown (event 1) is shown. At 4910 seconds, the RWAs slow down causing a constant rigid body response. Approximately forty seconds later, the ACS responds to the disturbance and begins to bring the spacecraft back.



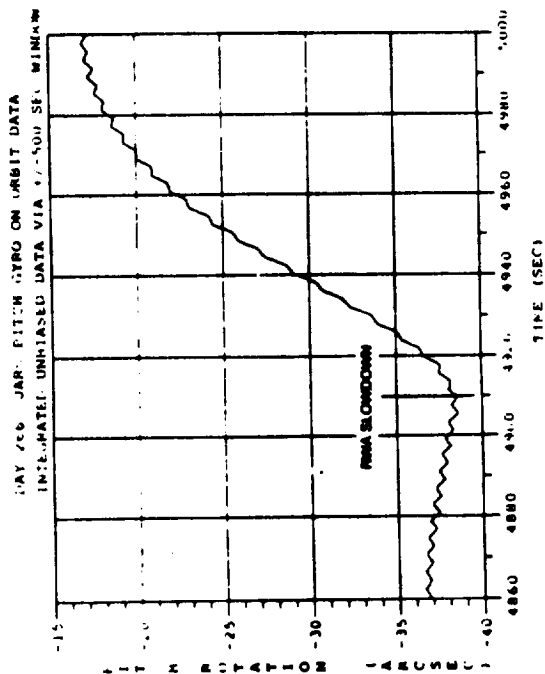
RWA SLOWDOWN

SPACECRAFT RESPONSE EVENT 1

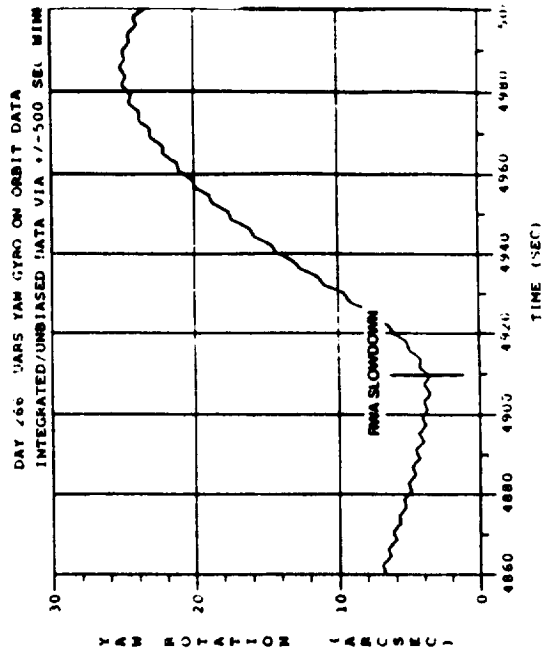
ROLL



PITCH



YAW



DAY 266 RWA SLOWDOWN

Spacecraft jitter over a two second window for the RWA slowdown event is shown. The largest jitter is in roll. Rigid body motion generates 2.2 arcseconds of jitter with the 0.25 Hz flatwise mode creating an additional 0.4 arcseconds. The 0.25 Hz flatwise mode is judged to be the primary flexible mode responding in each axis.

RWA SLOWDOWN

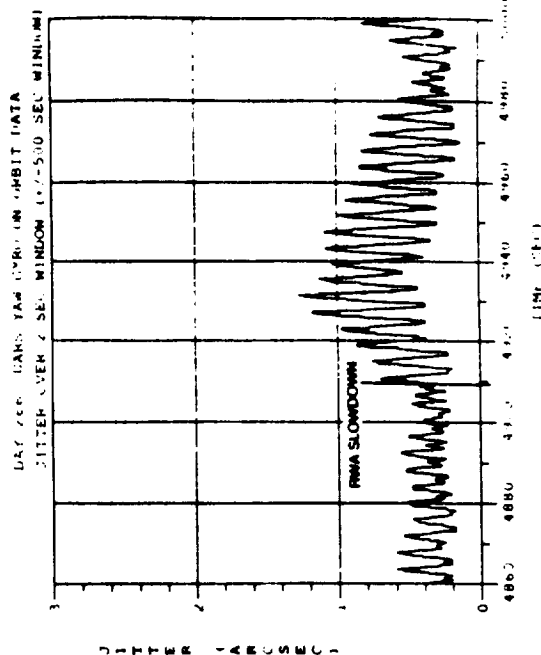
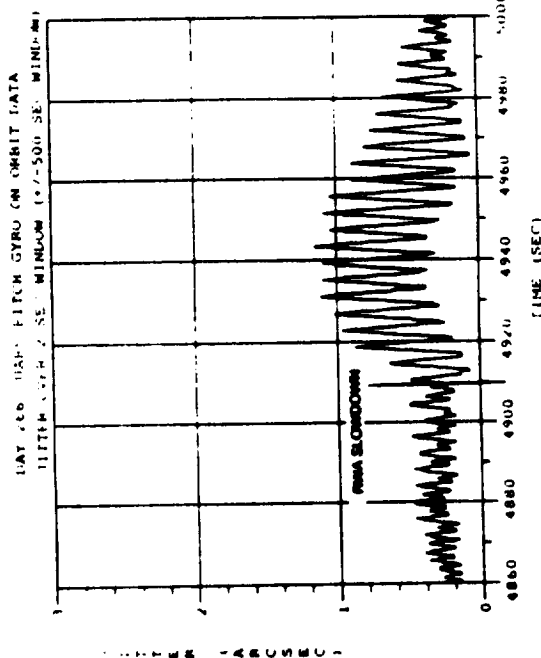
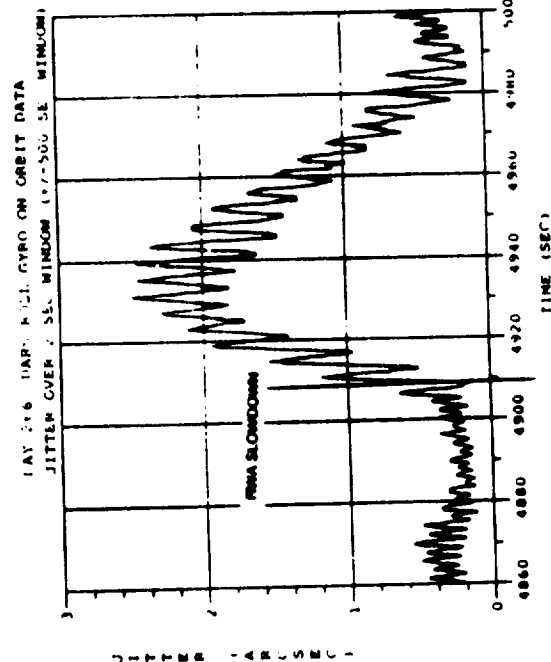


SPACECRAFT JITTER EVENT 1

ROLL

PITCH

YAW



DAY 266 SSPP BEGIN TRACKING

The spacecraft response for event 2, SSPP begin tracking, is shown. The SSPP alpha gimbal, which is lined up with the pitch axis, begins to track at 5025 seconds. The beta gimbal does not track. Only the spacecraft pitch response is altered by the SSPP event.

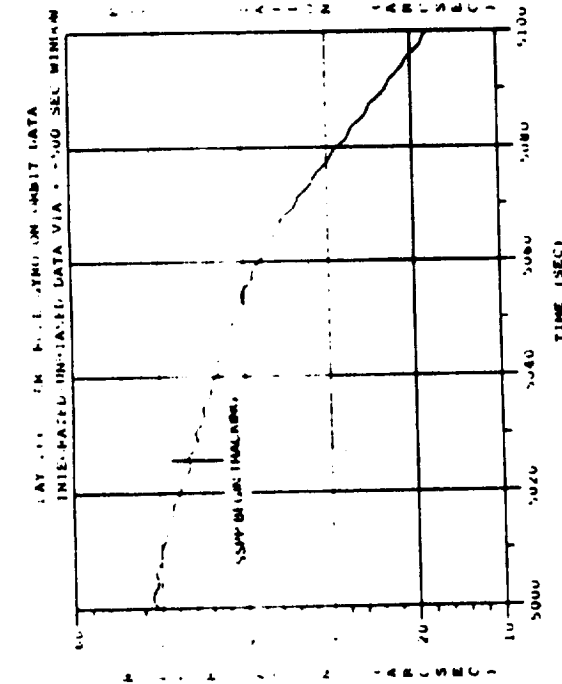
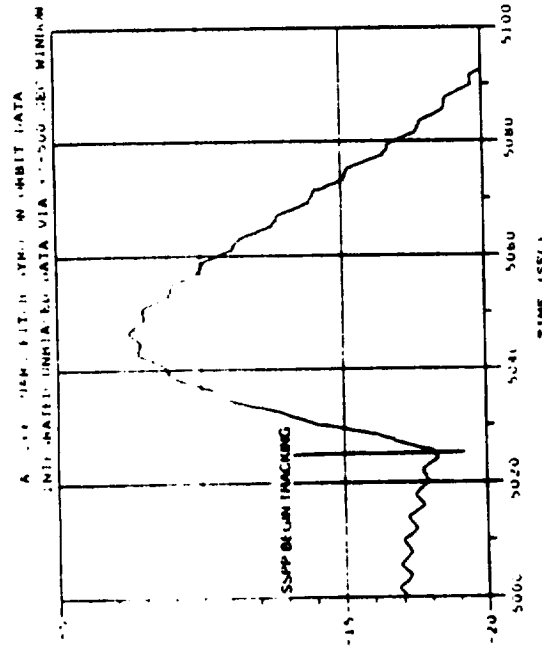
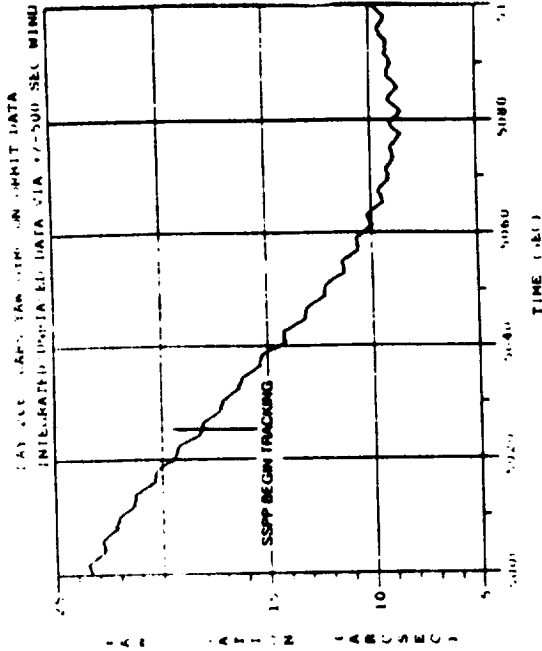
SSPP BEGIN TRACKING

SPACECRAFT RESPONSE EVENT 2

ROLL

PITCH

YAW



DAY 266 SSPP BEGIN TRACKING

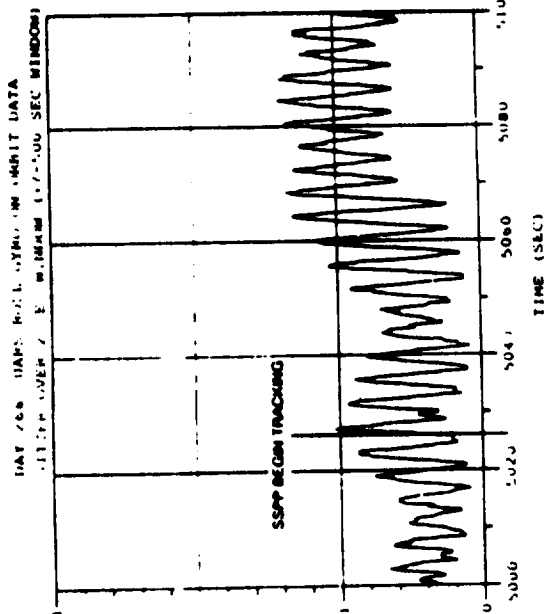
Spacecraft jitter over a two second window for the SSPP begin tracking event is shown. Only pitch jitter is affected by the event. Again the 0.25 Hz mode dominates the flexible spacecraft motion.



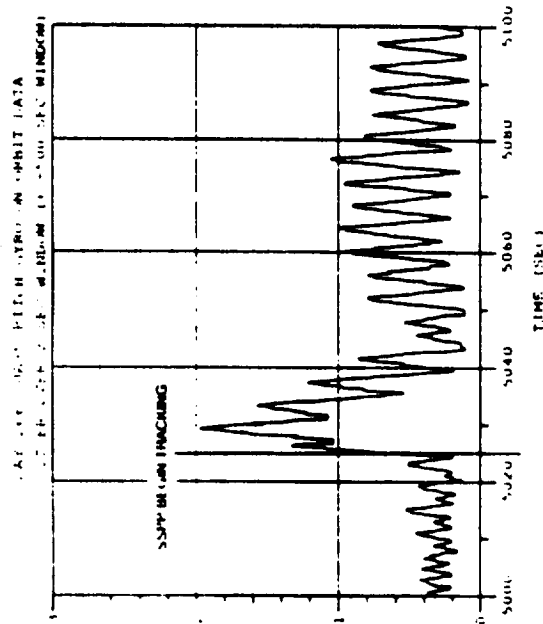
SSPP BEGIN TRACKING

SPACECRAFT JITTER EVENT 2

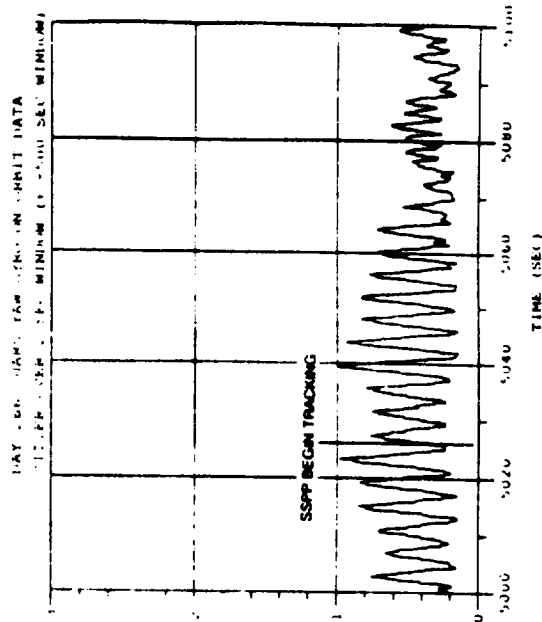
ROLL



PITCH



YAW



DAY 266 HGA REWIND

The spacecraft response for event 3, HGA rewind, is shown. The HGA alpha and beta gimbals begin to rewind at 5342 seconds. The greatest spacecraft response occurs about the roll and yaw axes. At time 5380 seconds, the spacecraft starts rotating in the opposite direction due to the ACS. The 0.25 Hz mode dominates the flexible portion of the motion.



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UARS JITTER STUDY

HGA REWIND

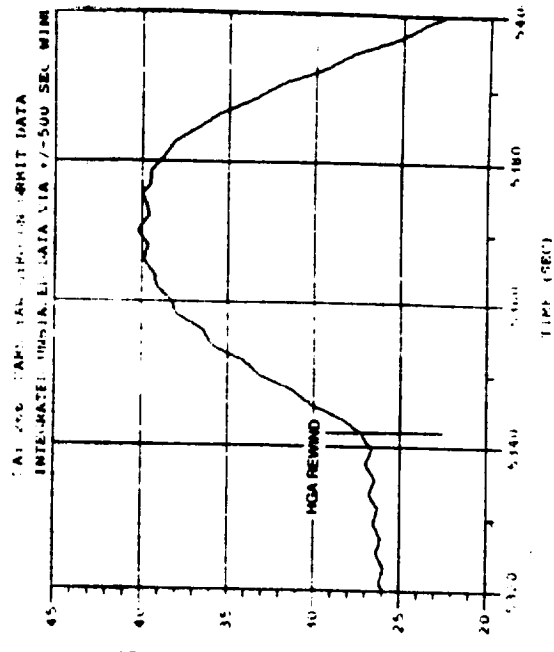
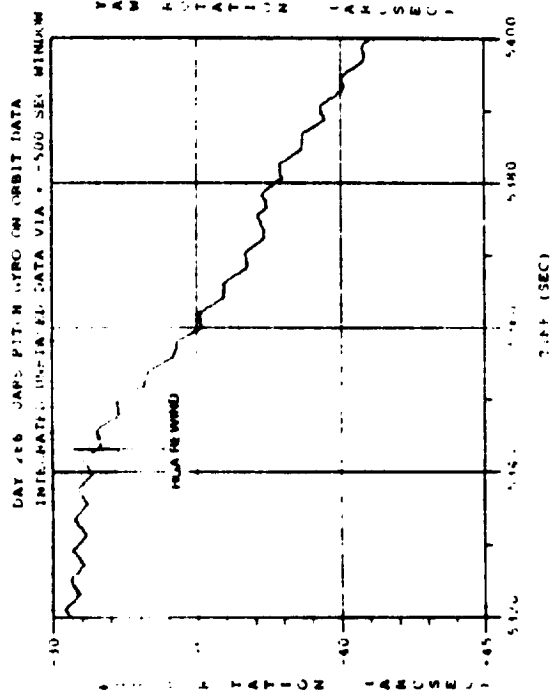
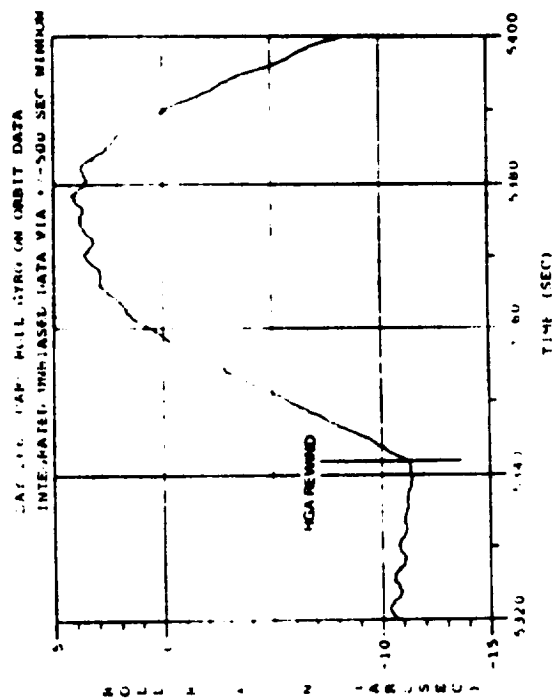
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SPACECRAFT RESPONSE EVENT 3

ROLL

PITCH

YAW



DAY 266 HGA REWIND

Spacecraft jitter over a two second window for the HGA rewind event is shown. Roll and yaw jitter are affected most by the event. Pitch jitter is also affected but to a smaller degree.



UARS JITTER STUDY

HGA REWIND

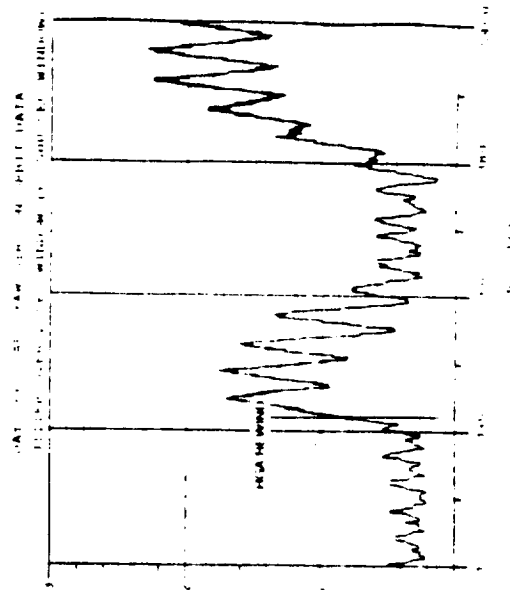
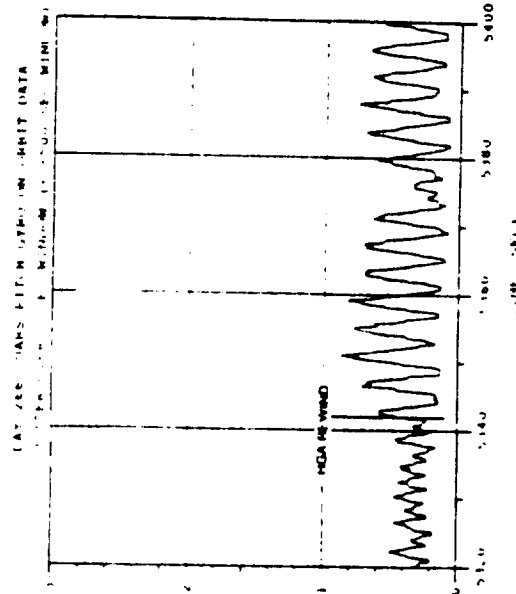
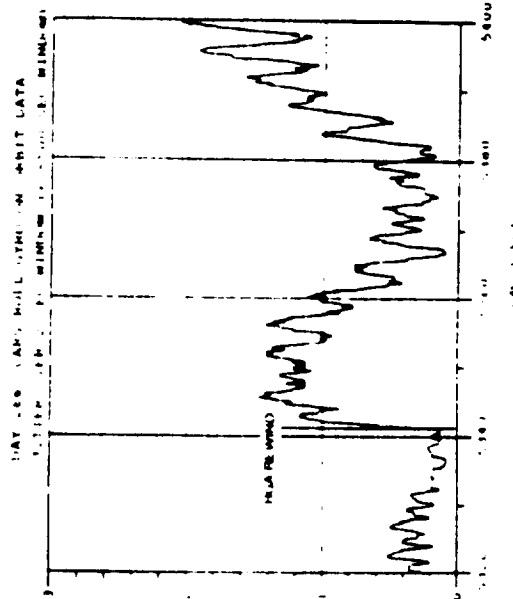
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SPACECRAFT JITTER EVENT 3

ROLL

PITCH

YAW



DAY 266 SSPP REWIND

The spacecraft response for the SSPP rewind events are shown. The first event, event 4, is the SSPP alpha gimbal stopping its motion. Spacecraft pitch responds to the event since the alpha gimbal is lined up with the pitch axis. At 5462 seconds, the SSPP alpha and beta gimbals start their rewind. The pitch and yaw axes respond most to the disturbance. At 5520 seconds, SSPP has stopped its rewind. Spacecraft yaw seems to be the only axis affected by SSPP stop disturbance.



UARS JITTER STUDY

SSPP REWIND

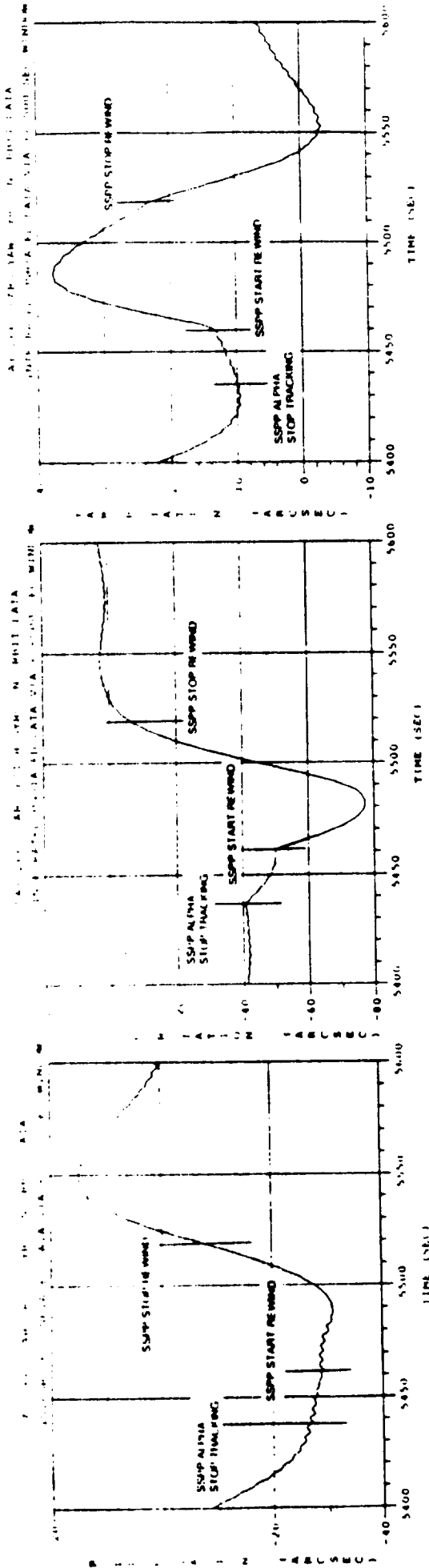
179

SPACECRAFT RESPONSE EVENTS 4, 5, AND 6

ROLL

PITCH

YAW



DAY 266 SSPP REWIND

Spacecraft jitter for the SSPP rewind events are shown. For the roll axis, peak jitter occurs when the SSPP stops its rewind. The jitter is caused by the ACS responding to previous disturbances, not the SSPP stop rewind event. Peak jitter for the pitch axis occurs at 5500 seconds. Again this jitter is not due to any event but rather by the ACS responding to previous disturbances.



UARS JITTER STUDY

SSPP REWIND

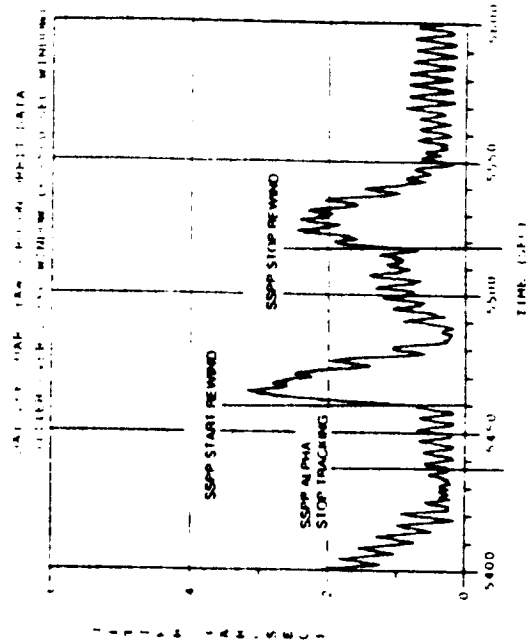
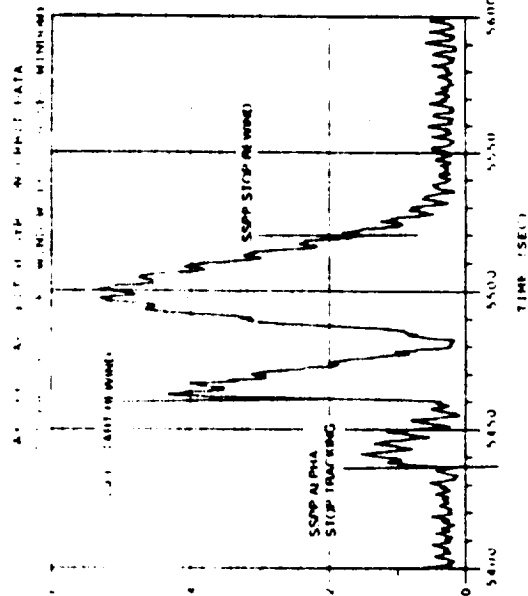
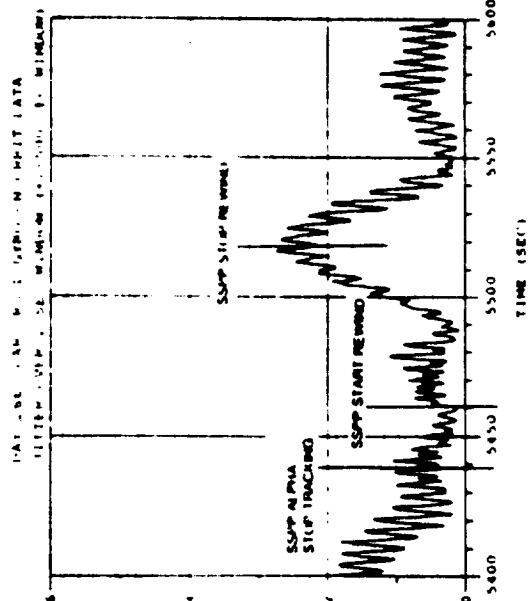
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SPACECRAFT JITTER EVENTS 4, 5, AND 6

ROLL

PITCH

YAW



DAY 266 HGA ALPHA STOP REWIND

The roll and pitch axes respond to the disturbance. There is no change in spacecraft yaw at the time of the disturbance.

HGA ALPHA STOP REWIND



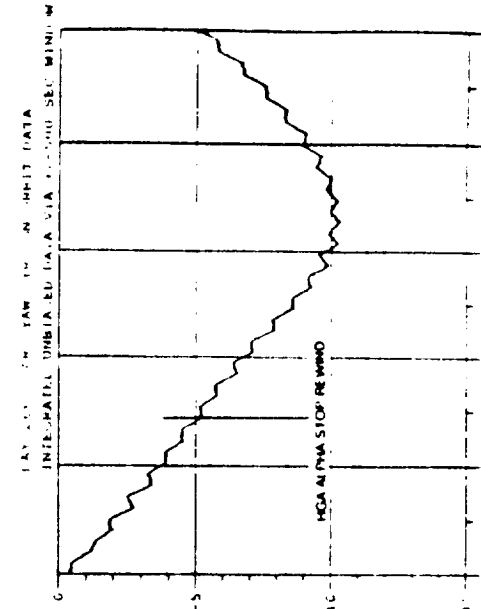
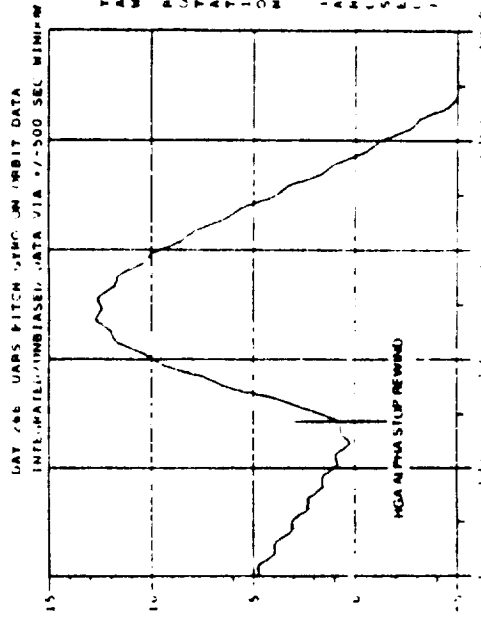
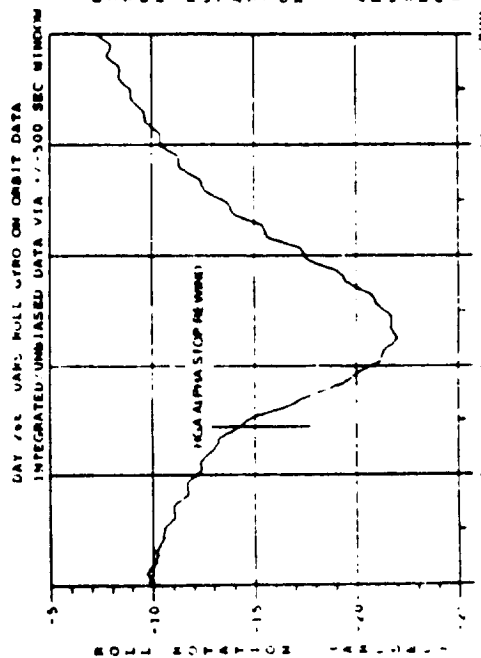
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SPACECRAFT RESPONSE EVENT 7

ROLL

PITCH

YAW



DAY 266 HGA ALPHA STOP REWIND

Spacecraft jitter increases in roll and pitch after the event. The increase in jitter at 5760 seconds is due to the ACS.



UARS JITTER STUDY

HGA ALPHA STOP REWIND

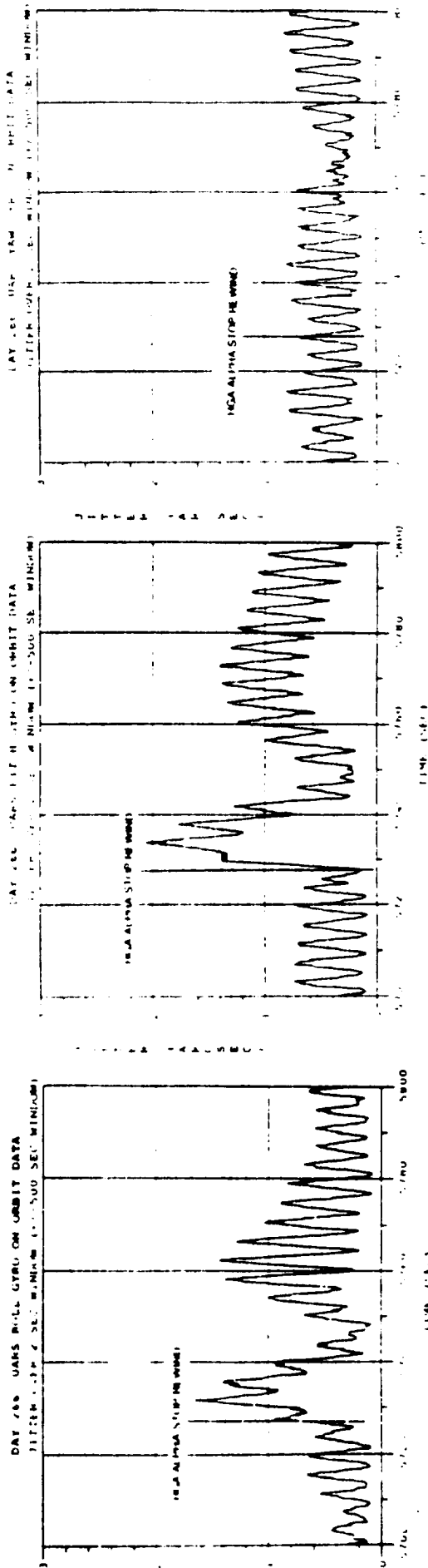
185

SPACECRAFT JITTER EVENT 7

ROLL

PITCH

YAW



DAY 266 SSPP BEGIN TRACKING

The SSPP alpha gimbal, which rotates about the pitch axis, begins to track at 6351 seconds. The greatest spacecraft response is in the pitch axis.



UARS JITTER STUDY

SSPP BEGIN TRACKING

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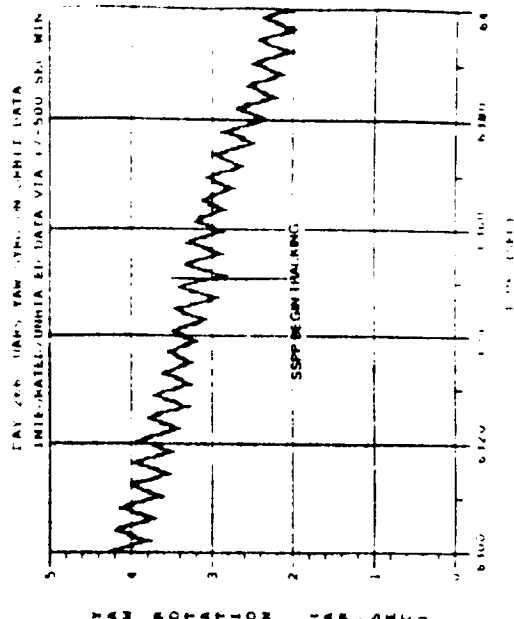
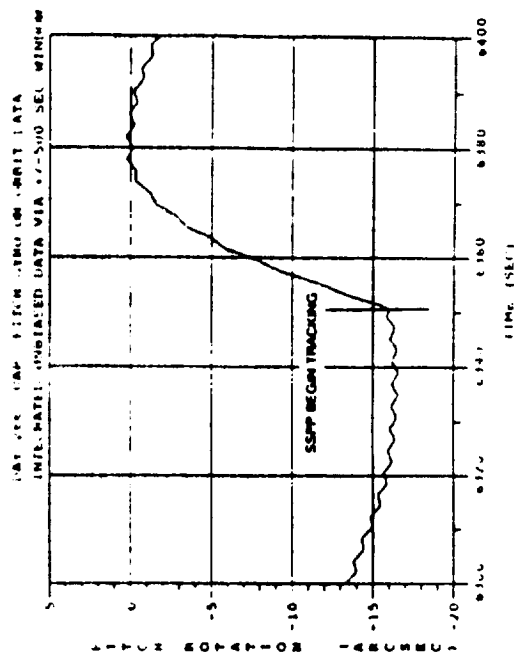
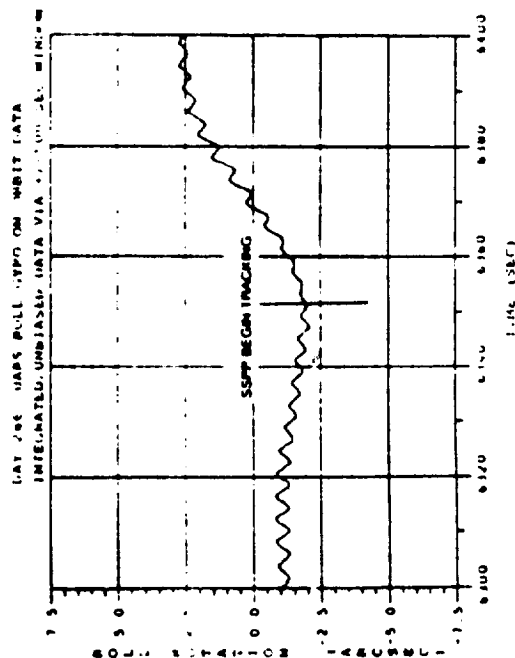
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SPACECRAFT RESPONSE EVENT 8

ROLL

PITCH

YAW



DAY 266 SSPP BEGIN TRACKING

A significant increase in pitch jitter occurs after the event. Roll jitter also increases slightly but there is no change in yaw jitter. The 0.25 Hz mode dominates the flexible portion of the motion.



UARS JITTER STUDY

SSPP BEGIN TRACKING

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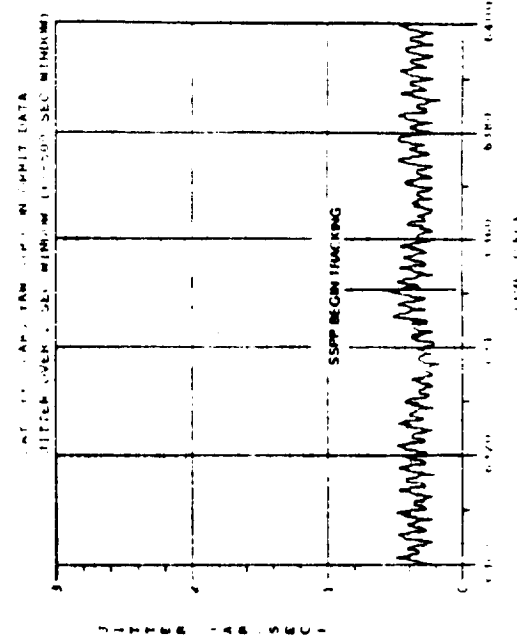
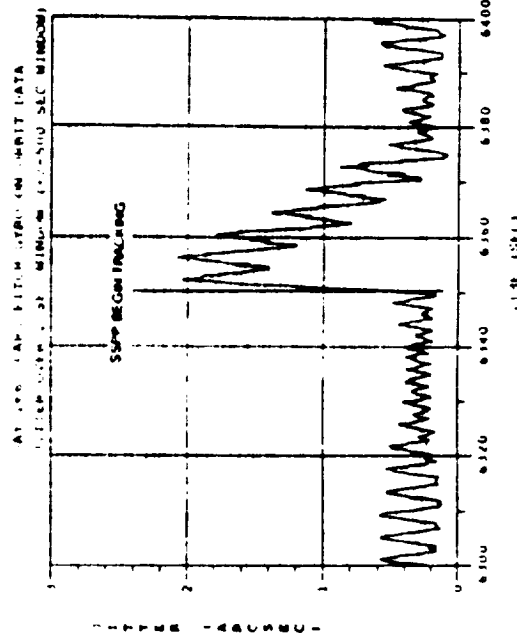
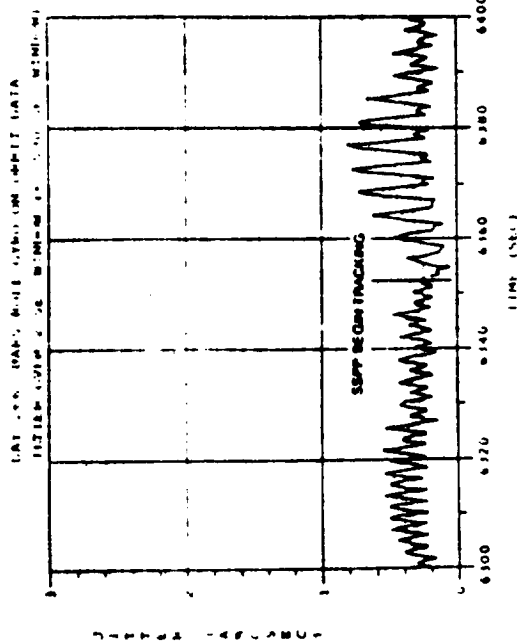
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SPACECRAFT JITTER EVENT 8

ROLL

PITCH

YAW



DAY 266 JITTER SUMMARY

Jitter for the eight disturbances are summarized. Rewind events create more jitter than tracking events due to greater slew rates. The SSPP, with the largest inertia, creates the greatest jitter.

For each of the eight events, jitter is due primarily to rigid body motion.



UARS JITTER STUDY

DAY 266 JITTER SUMMARY

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EVENT #	EVENT DESCRIPTION	ROLL JITTER (ARCSEC/2 SEC)	PITCH JITTER (ARCSEC/2 SEC)	YAW JITTER (ARCSEC/2 SEC)
1	RWA slowdown	2.5	1.2	1.3
2	SSPP α start tracking	1.0 *	2.0	1.0 *
3	HGA α & β start rewind	1.5	0.8	1.8
4	SSPP α stop tracking	1.0 *	1.6	0.5 *
5	SSPP α & β start rewind	0.7	4.3	3.3
6	SSPP α & β stop rewind **	2.7 *	5.2 *	2.4
7	HGA α stop	1.6	2.1	0.6 *
8	SSPP α start tracking	0.8	2.1	0.5 *

* No increase in jitter due to disturbance

** Jitter for SSPP rewind stop is primarily due to the control system responding to previous disturbances

LARGE RIGID BODY RESPONSE FOR EACH DISTURBANCE

DAY 128 FLIGHT JITTER AND HRDI CALIBRATION SLEW CORRELATION

A visual inspection of flight data for Day 128 (January 17, 1992) was made to determine if any discernable jitter is created by disturbances from HALOE, HRDI, or WINDII. Other disturbance sources for Day 128 include the solar array drive, HGA, SSPP, and MLS. An analytical correlation was performed for the HRDI calibration slew maneuver.



DAY 128 FLIGHT JITTER AND HRDI CALIBRATION SLEW CORRELATION

HALOE

The Halogen Occultation Experiment (HALOE), developed at NASA Langley, has a Cassegrain telescope which can scan (relative to the spacecraft axes) in both azimuth and elevation. The telemetry data points are outputs from potentiometers which measure the rotational angles of the gimbal motors which drive the telescope.

The GE database acronyms for azimuth and elevation are HAAZIM and HAELEV. Telemetry is downlinked at a data rate of a sample every 1/8 UARS seconds. HALOE collects science data only at 'Sunrise' and 'Sunset'. The telescope excursions exhibited on the graph are sunrise and sunset data collection events. Between events the telescope is stowed.

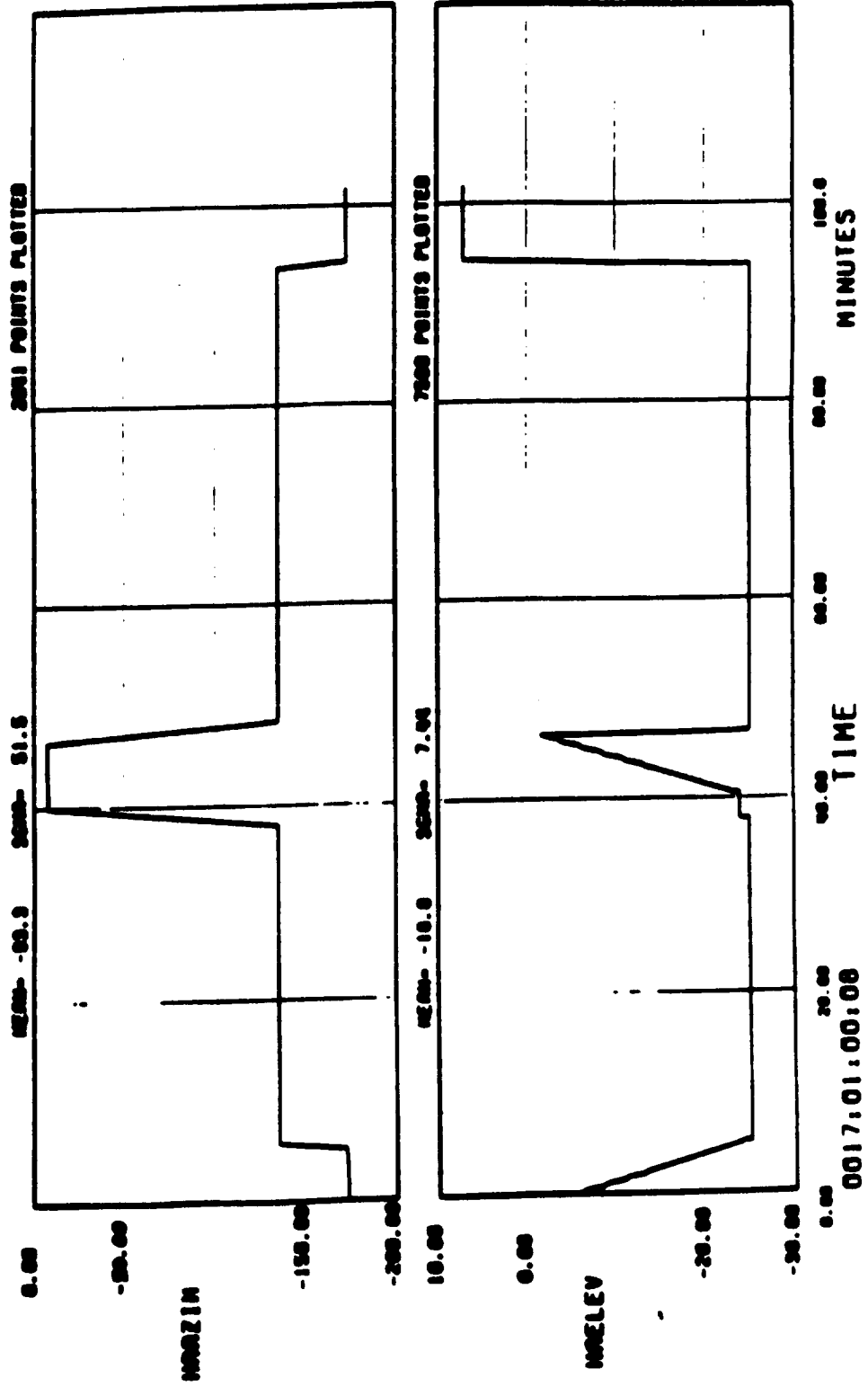
The potentiometer resolutions in azimuth and elevation are 0.1 and 0.011 degrees in azimuth and elevation, respectively.



UARS JITTER STUDY

HALOE FLIGHT DAY 128

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HRDI

The High Resolution Doppler Imager (HRDI) instrument has a telescope which can scan (relative to the spacecraft axes) in both azimuth and elevation. The telemetry data points are outputs from optical encoders which measure the rotational angles of the gimbal motors which drive the telescope.

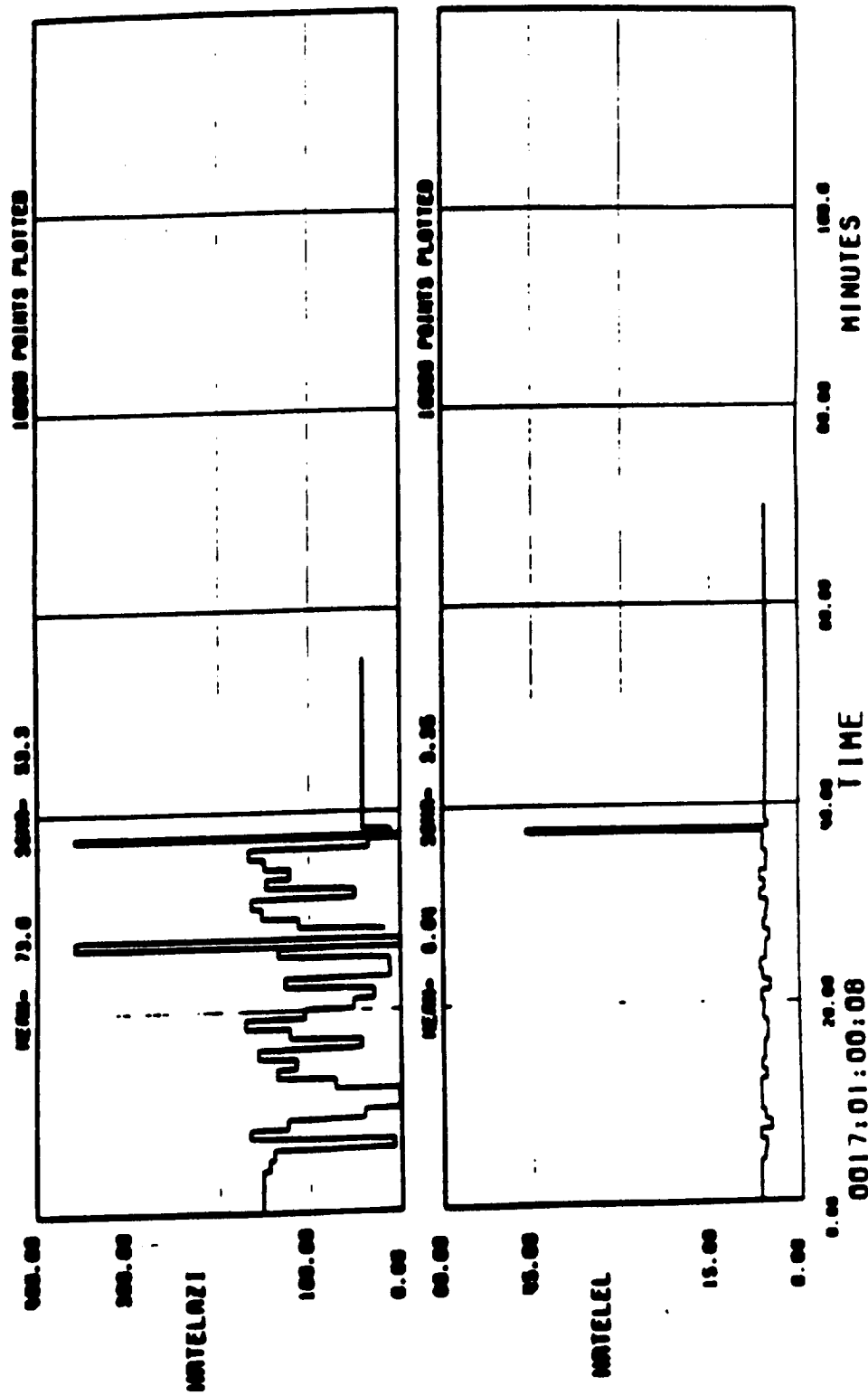
The GE acronyms for azimuth and elevation are HRTELAZI and HRTELEL. The telemetry is downlinked at a data rate of one sample every 1/8 UARS second. HRDI essentially scans continuously via instructions loaded up daily to the spacecraft. The optical encoder resolutions in azimuth and elevation are 0.0003 degrees in both azimuth and elevation.



UARS JITTER STUDY

HRDI FLIGHT DAY 128

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WINDII

The Wind Imaging Interferometer (WINDII) measures atmospheric temperatures and winds in the 550 to 780 nm range. There are three forms of internal mechanical movements: (1) an aperture with two possible positions, (2) a calibration mirror with two possible positions, and (3) a filter wheel with eight possible positions. Each of the three movements involve very small inertias that do not generate much of a disturbance.

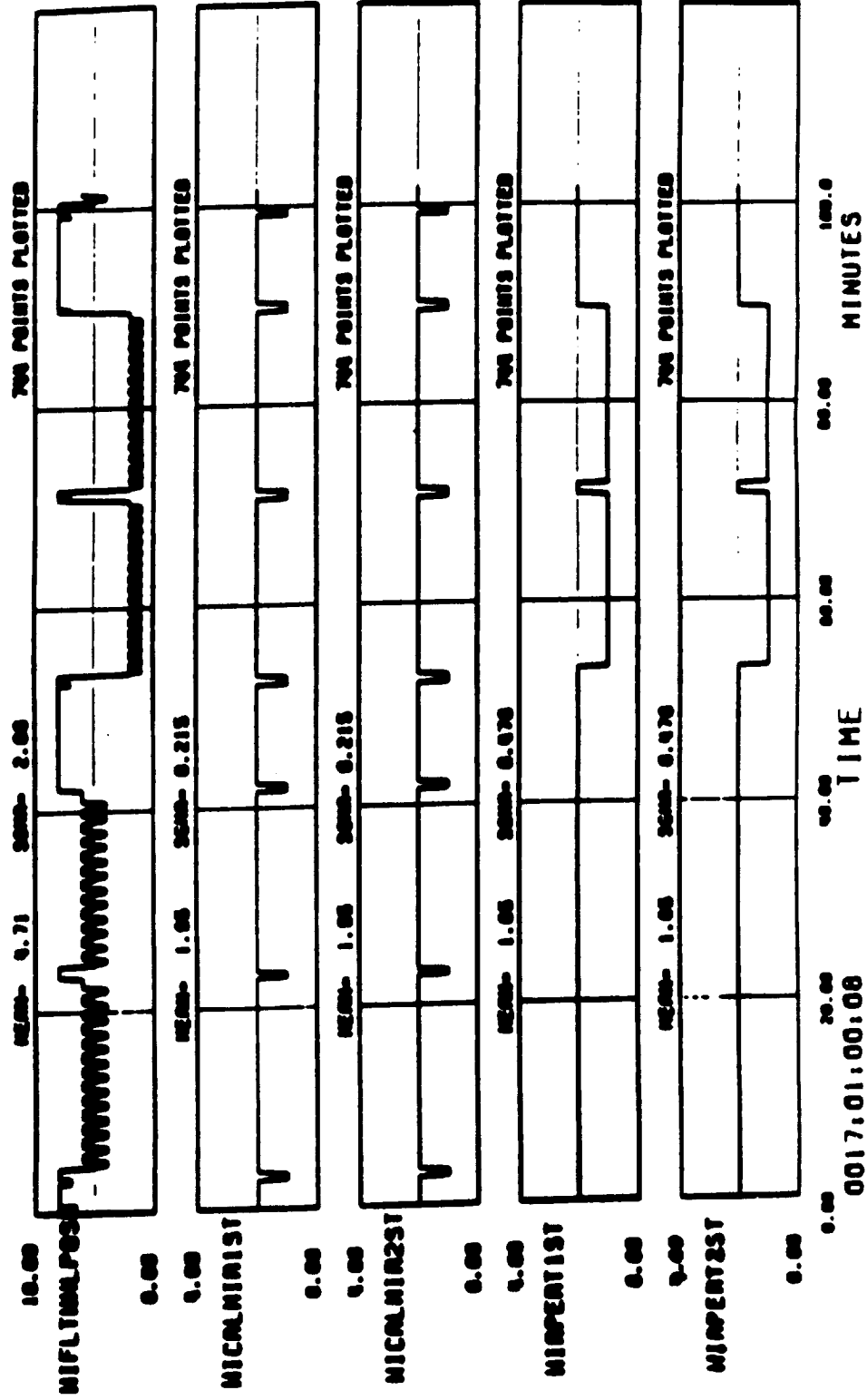
The GE database acronyms for the aperture, mirror, and filter are WIAPERT1(2)ST, WICALMIR1(2)ST, and WIFLTHLPOSN respectively. All data is downlinked every 2 UARS seconds.



UARS JITTER STUDY

WINDII FLIGHT DAY 128

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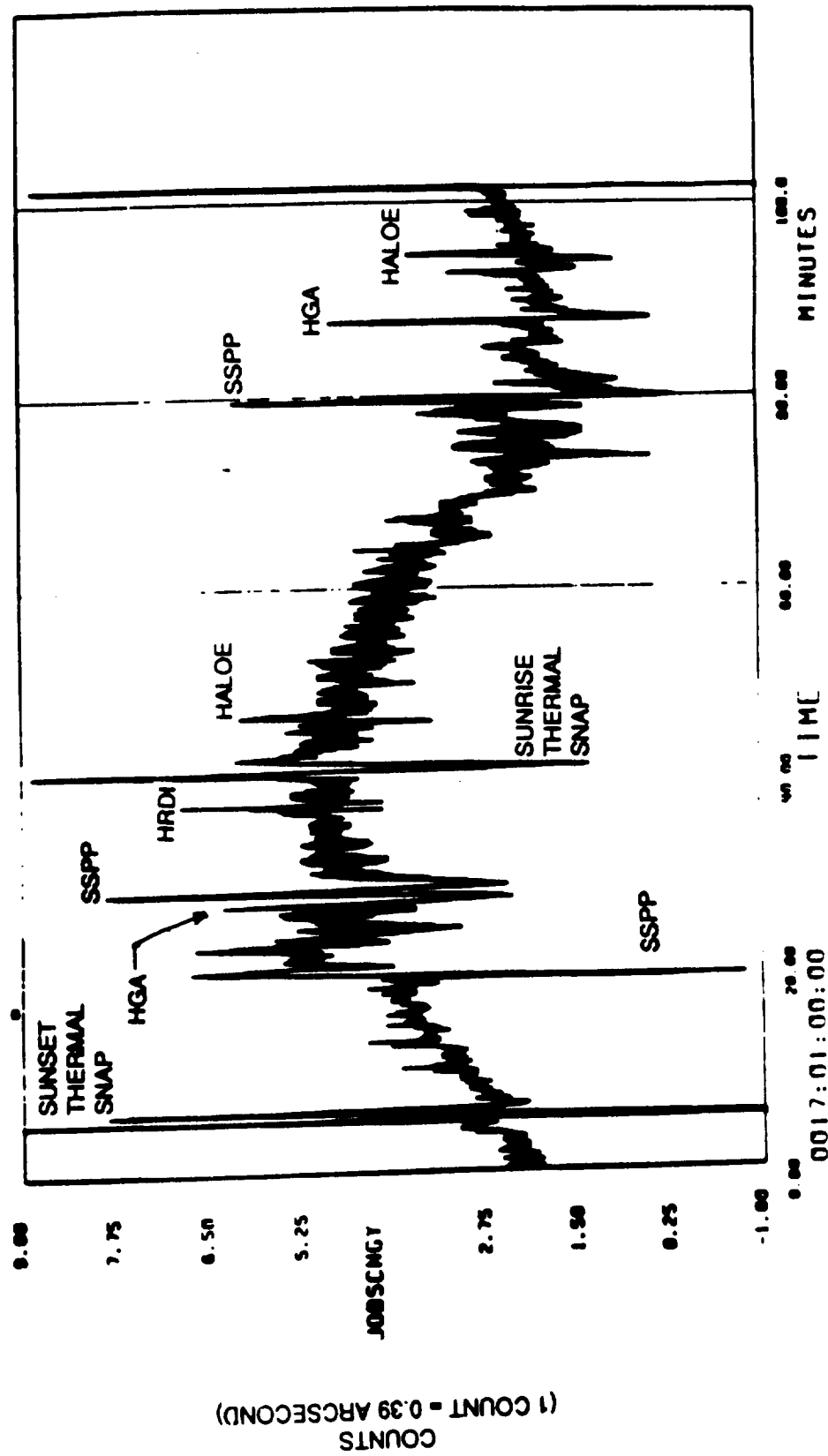


VISUAL CORRELATION OF SUBSYSTEMS AND INSTRUMENTS (PITCH GYRO DAY 128)

Pitch gyro data for the 100 minute time span on DAY 128 is presented. The gyro data is averaged to 1 UARS second. Disturbances from both HALOE and HRDI generate a significant spacecraft rigid body response. WINDII, because of its small disturbance level, does not create any detectable gyro response. Jitter induced from HGA and SSPP is also seen.



VISUAL CORRELATION OF SUBSYSTEMS AND INSTRUMENTS

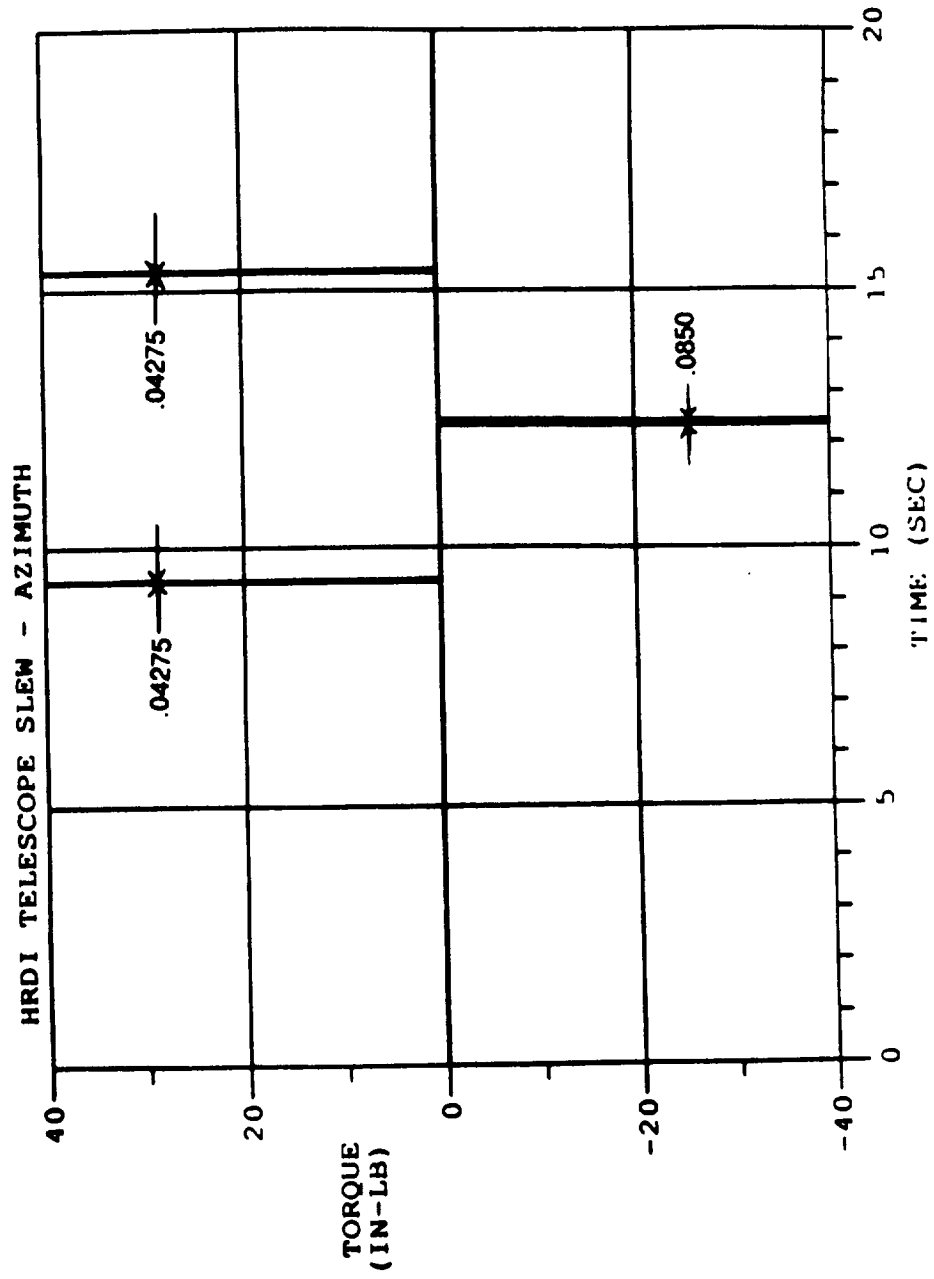


HRDI CALIBRATION SLEW ANALYTICAL MODEL

HRDI takes 3 seconds to slew 45 degrees in the azimuth direction and another 3 seconds to return to its original position. A torque of 40 in-lbs was applied for a duration of 0.04275 seconds to obtain the proper telescope speed.



HRDI CALIBRATION SLEW TORQUE PROFILE



CORRELATION OF HRDI CALIBRATION SLEW

At time 9 seconds, HRDI begins the slew maneuver. The maneuver is completed at approximately time 15 seconds.

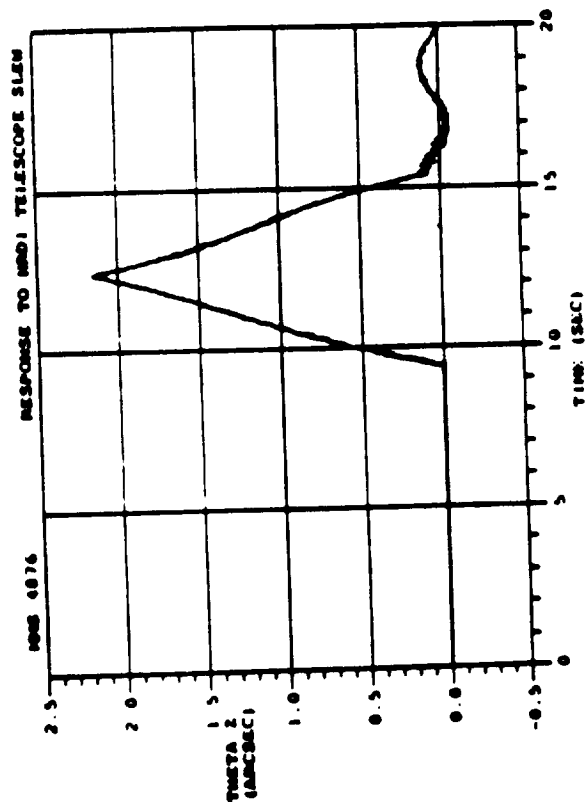
The dynamic response at the gyro location was determined analytically and compared to flight data. The response is mainly rigid body motion about azimuth (spacecraft Z). The total rigid body motion is 2.2 arcseconds in both the analytical and flight data.

The response seen in the flight data before time 9 seconds (when HRDI begins its slew maneuver) is due to the solar array drive continuously exciting the 0.25 Hz flatwise solar array mode. This disturbance is not modeled in the analytical prediction.



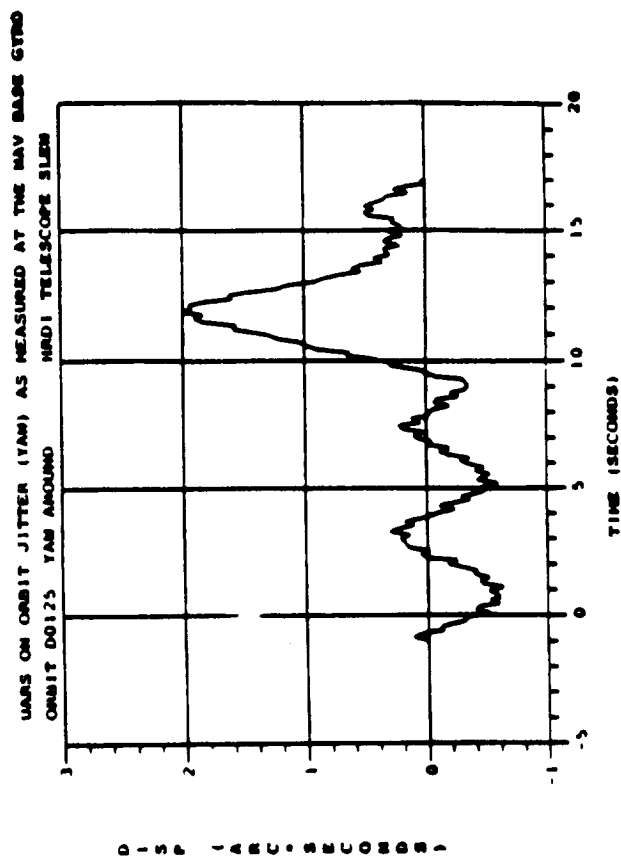
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ANALYTICAL RESPONSE



Jitter calculated in 2 seconds
time window = 1.47 arcsec.

FLIGHT RESPONSE



Jitter calculated in 2 seconds
time window = 1.83 arcsec.

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CONCLUSIONS AND LESSONS LEARNED

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CONCLUSIONS

Results from the study are presented in the facing conclusions chart. The most significant result of this study was the excellent agreement between measured flight jitter and the predicted jitter after using the measured damping value (2.8%) in the analytical model. The conservative value (0.2%) used in prelaunch analysis predicted a greater amount of jitter than actually seen in flight. This gives GE Astio high confidence in assuring jitter performance meets specifications for future large pointing platforms such as EOS when requirements are met using the conservative damping value in all of the pre-launch analysis.



CONCLUSIONS

- GOOD AGREEMENT BETWEEN ANALYTICAL FREQUENCY PREDICTIONS AND FLIGHT DATA
- S/A FLATWISE FREQUENCY DOES NOT CHANGE WITH S/A POSITION AS MUCH AS ANALYSIS PREDICTS (FLIGHT FREQUENCY ALWAYS WITHIN 10% OF ANALYTICAL)
- S/A EDGEWISE FREQUENCY DOES CHANGE WITH POSITION AS THE ANALYSIS PREDICTS
- CONSISTENT DAMPING VALUE OF 2.8% FOR FLATWISE MODE DETERMINED FROM FLIGHT DATA
- EXCELLENT CORRELATION BETWEEN ANALYTICAL AND FLIGHT JITTER DUE TO MLS DISTURBANCE AFTER MODEL CORRECTION USING IN-ORBIT DERIVED DAMPING VALUES
- CONSERVATIVE PRE-LAUNCH DAMPING ESTIMATE OVER PREDICTS JITTER BY FACTOR OF 3
- JITTER FROM SOLAR ARRAY DRIVE FAR EXCEEDS JITTER FROM ANY INSTRUMENT
- PSD ANALYSIS GIVES FREQUENCY CONTENT AS WELL AS STRENGTH OF MODAL RESPONSE ENABLING CORRELATION OF HIGHER ORDER MODES
- NOMINAL OPERATION OF REACTION WHEELS HAS A SMALL JITTER CONTRIBUTION
- HGA AND SSPP DISTURBANCE EVENTS RESULT IN PRIMARILY RIGID BODY MOTION
- EXCELLENT CORRELATION OF HRDI CALIBRATION SLEW

EXCELLENT CORRELATION WITH FLIGHT MODAL CHARACTERISTICS AND JITTER AFTER MODEL CORRECTION USING MEASURED DAMPING VALUES PROVIDES CONFIDENCE IN PREDICTING JITTER FOR OTHER LARGE POINTING PLATFORMS SUCH AS EOS

LESSONS LEARNED

The most difficult portion of the study was identifying flight modes. Significant engineering judgement had to be made because of the limited instrumentation. Additional instrumentation would significantly improve the ability to identify modes.



LESSONS LEARNED

- GYRO RESOLUTION OF 0.05 ARCSEC MAY NOT BE SUFFICIENT TO ADEQUATELY MEASURE DAMPING ESPECIALLY FOR HIGHER ORDER MODES
- GYROS ARE SUBJECT TO DRIFT RATE ERRORS WHICH MUST BE REMOVED FROM INTEGRATED DATA TO CALCULATE ACTUAL FLIGHT POSITION. THE ERROR WAS REMOVED WITH DATA AVERAGING WHICH MAY INDUCE SOME ERRORS.
- GYROS ARE LOW FREQUENCY SENSORS THAT WILL NOT BE ADEQUATE FOR MEASURING HIGH FREQUENCY DISTURBANCES SUCH AS STIRLING COOLERS.
- LIMITATION OF LOOKING AT RESPONSE ONLY AT MMS (GYRO LOCATION) MADE MODE IDENTIFICATION DIFFICULT. STRATEGIC PLACEMENT OF SENSORS WOULD SIGNIFICANTLY IMPROVE ABILITY TO IDENTIFY MODES.

INSTRUMENTATION WITH ADEQUATE FREQUENCY RANGE, RESOLUTION, AND PLACEMENT IS IMPORTANT TO ON-ORBIT CHARACTERIZATION

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